ISSN 0705-5927

CANADIAN LAND RECLAMATION ASSOCIATION

PROCEEDINGS
OF THE
TWELFTH ANNUAL MEETING

CLRA ACRSD '87

COMPTES-RENDUS
DE LA
DOUZIÈME RÉUNION ANNUELLE

ASSOCIATION CANADIENNE DE RÉHABILITATION DES SITES DÉGRADÉS

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Laurentian University / Université Laurentienne
Sudbury, Ontario

June 7 - 11 juin 1987

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PROCEEDINGS

OF

THE TWELFTH ANNUAL MEETING

"EVERYTHING UP TO DATE IN RECLAMATION"

edited by / sous la direction de

P.J.Beckett

"MISE A JOUR DES DÉVELOPPEMENTS EN RÉHABILITATION DES SITES DÉGRADÉS"

COMPTES-RENDUS

DE LA

DOUZIÈME RÉUNION ANNUELLE

ASSOCIATION CANADIENNE DE RÉHABILITATION DES SITES DÉGRADÉS

Laurentian University / Université Laurentienne

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FOREWORD

"Everything Up-to-Date in Reclamation"

In the nine intervening years since the Third Annual Meeting of the Canadian Land Reclamation Association was held in Sudbury in 1978, there has been a multiple quantum leap forward in all facets of reclamation knowledge, technology, practice and public interest.

This progress is reflected in the wide range of information which is presented by the speakers at the conference and the developments observed on the field trips. In 1978, the highlight of the field trips was the local work on tailings reclamation and the early experimental work being done on the "Greening of Sudbury" program. This time the giant strides taken to produce the large area of land reclaimed and the knowledge gained in the latter program will be evident. Aside from the achievement in the field situation, it is noteworthy that the accomplishments are the result of concerted co-operation between the three levels of government (federal, provincial and municipal), the local educational institutions (Laurentian University and Cambrian College), local industries, large and small, and the people of the Sudbury region. This work, along with the tailings revegetation, has attracted world wide attention.

The local committee hopes your visit to Sudbury will be both meaningful and enjoyable.

Tom Peters
Chairman, Local Organizing Committee

AVANT-PROPOS

Mise à jour des développements en réhabilitation des sites dégradés

Neuf ans se sont écoulés depuis la troisième réunion annuelle de l'Association canadienne de réhabilitation des sites dégradés, tenue à Sudbury en 1978. Durant cette période, nous avons considérablement accru nos connaissances dans le domaine de la réhabilitation des sites dégradés, et progressé à pas de géant en matière de technologie, de pratique et d'intérêt public.

Toute la gamme d'information fournie par les conférenciers, ainsi que les améliorations observés lors des enquêtes sur le terrain, témoignent de ces progrès. Le travail local de réhabilitation des sites de déversement des scories et le travail expérimental effectué dans le programme de "Fertilisation de Sudbury" constituaient, en 1978, le point marquant de ces enquêtes. Cette fois-ci, les grands moyens employés pour réhabiliter les vastes sites dégradés et les connaissances acquises lors de l'exécution de ce programme sauteront aux yeux. Il faut de plus souligner que ces accomplissements sont le fruit d'une collaboration concertée entre les trois paliers de gouvernement (fédéral, provincial et municipal), les établissements locaux d'enseignement (l'Université Laurentienne et le Collège Cambrian), les petites et grandes industries locales, et les habitants de la région de Sudbury. Nos recherches ainsi que la fertilisation des aires de scories ont attiré l'attention du monde entier.

Le Comité local espère que votre visite à Sudbury sera à la fois enrichissante et attrayante.

Tom Peters
Comité organisateur local

RECLAMATION PROGRAMS AND RESEARCH AT FALCONBRIDGE LIMITED'S SUDBURY OPERATIONS*

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ABSTRACT

Falconbridge Limited has an ongoing reclamation program that utilizes a systems approach to waste management. This involves the integration and utilization of wastes from various units in the operation to optimize the cost/benefit ratio. Current research is also directed at establishing a long term abandonment strategy for acid generating materials, by proper management and/or establishing oxygen barriers.

INTRODUCTION

Falconbridge Limited at Sudbury, Ontario, is currently in the midst of various research projects that are trying to answer some fundamental questions and concerns with tailing abandonment. The main concern is with a perpetual care and treatment system being required to achieve acceptable seepages. Solutions to these environmental problems must be economical for the mining industry to remain competitive and viable. For this reason, a systems approach method is developed to better manage any resources and/or wastes. Overburden, for example, which had to be removed from an open pit was used to reclaim several hectares of tailing and slag piles. Waste scrap, wood and construction rubble is utilized for erosion control or tailing reclamation. By proper planning, management and research, cost effective methods are implemented to solve environmental problems.

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

RECLAMATION WORK AT FALCONBRIDGE

Tailing Areas

Approximately 55 hectares of tailing and pyrrhotite disposal sites have been successfully re-vegetated with various grasses, legumes and trees. Past research showed that the least cost method for establishing vegetation on tailing was by the placement of a 30 cm. sand gravel overburden (8). This was economical for Falconbridge because the overburden in most cases originated from an open pit excavation and needed to be disposed at no cost to the reclamation project. Lime consumption was therefore greatly reduced to 20 tonnes/hectare versus 150-200 tonnes/hectare. Also due to the coarse nature of the overburden, the capillary movement of water was arrested, preventing the upward migration of metallic salts into the root zone. This resulted in acceptable plant growth with very little maintenance requirements.

Recent monitoring programs and research is unfortunately revealing that a vegetative cover on sulphide base metal tailing does not stop acid generation. Oxidation of predominantly iron sulphides results in the production of sulphuric acid which in turn dissolves heavy metals from the tailing and pyrrhotite. This oxidation reaction is greatly accelerated by the presence of bacteria such as thiobacillus ferooxidans. A vegetative cover of grasses and trees does not prevent the tailing from generating acidic seepages to a depth of several metres.

Current research is therefore directed towards solving this problem by developing an economical environmentally acceptable solution.

Tailing waste at Falconbridge is composed of two constituents of approximately equal quantities; tailing slimes and pyrrhotite (Fe_7S_8) . The tailing slimes contain less sulphur and mineralization than the pyrrhotite and therefore generate less acid. Table 1 shows the respective composition of both materials.

Table 1 - Chemical composition of Po and Tailing (%)

	Pyrrhotite	Tailing
Nickel	0.9	0.08
Copper	0.06	0.08
Sulphur	35	1.15
Iron	55	10
Cobalt	0.02	
Insolubles	-	81

Although both waste materials are produced as separate products in the concentrator they are blended and jointly disposed to a common site. The finer tailing slimes dilute the more reactive pyrrhotite and minimize leaching. As the mines near completion a tailing close out strategy has been developed to facilitate abandonment by reducing acid generation. The more reactive pyrrhotite is impounded separately during the final 1-2 years, while the tailing slimes continue to be disposed in the tailing area. This results in a less reactive cover of 30 to 100 cm. of slimes over the tailing pyrrhotite mix. By depositing a sufficient cover of slimes then oxidation of the pyrrhotite is greatly reduced. The smaller pure pyrrhotite deposit may then be covered with several metres of overburden. This method greatly reduces costs where overburden material is scarce.

Wasterock Management

Wasterock consists of barren and mineralized rock that is not profitable and is therefore discarded. During the past, wasterock was considered relatively inert and was disposed, or utilized as a fill material, without regard for the environment. Recent studies have shown that wasterock, due to some mineralization and sulphur content, can generate acid and dissolved metals to the same degree as tailing areas. This realization has led Falconbridge to manage wasterock in a similar fashion as tailing for treatment, reclamation, and abandonment purposes. A wasterock management strategy has been developed to ensure that all seepages are within the drainage basin of a treatment system.

A 100 hectare scale test has been implemented by placing 2 meters of wasterock on top of an inactive tailing area. The wasterock being much coarser than the tailing (up to minus 15 cm.) will prevent upward migration of metallic salts. The wasterock has then been ameliorated to prevent leaching and enhance the establishment of a vegetative cover. Currently under investigation is the application of sewage sludge, various fertilizer and lime treatments and waste alkaline material from a pulp and paper company. All three large scale test plots are attempting to block oxygen from contacting the iron sulphides as well as inhibiting bacterial activity. Vacuum tensiometers installed in these test plots will permit the collection of seepage water to evaluate the effectiveness of the various treatments.

Conservation Area

Adjacent to the smelter complex was a totally denuded bog several hundred hectares in size. This bog, once a sphagnum peat bog with cedars and black spruce, had been destroyed by fires and early smelting activities. Recolonization had not occurred due to metal and SO_2 toxicity from smelter emissions. Falconbridge Limited directed treated alkaline wastewater into this bog to settle out any suspended solids prior to discharging to the natural watercourse. The treated wastewater neutralized the existing acidity and reduced the toxicity by rendering heavy metals insoluble. This resulted in a natural re-colonization by aquatic macrophytes, mostly typha angustifolia (cattails). So successful was this transformation that in just 9 years, since 1978, over 80% of the area is covered with cattails.

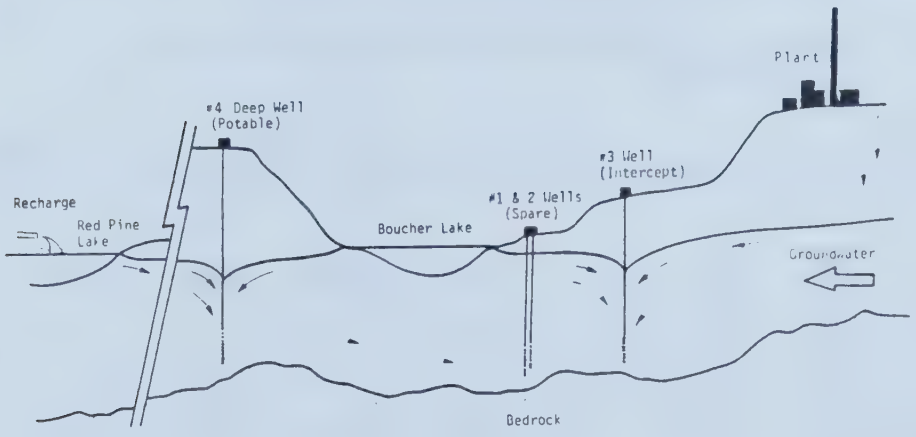
This new marsh is now providing a habitat for numerous birds and aquatic fowl, ducks, geese, killdeer, marsh hawks, great blue herons and red winged blackbirds. Small fish such as minnows, suckers and sticklebacks have been observed as well as mammals such as muskrats, beavers, moose and foxes.

A further benefit has been the enhanced treatment of the effluent flowing through the marsh. Not only are suspended solids filtered out, but a further removal of dissolved nickel and iron is taking place during the summer months. It is suspected that bacteria and/or algae are responsible for the removal of these dissolved metals by an active uptake mechanism. Due to the success of this wetland as a tertiary treatment system, research is currently underway to evaluate the feasibility of utilizing wetlands for tailing reclamation or as passive downstream treatment systems.

Red Pine Lake

A small 4 hectare lake located next to the Conservation Area was devoid of any life for the same reasons as the Conservation Area had been. Falconbridge began pumping 2,000 litres/minute of Wanapitei river water into Red Pine lake to recharge the nearby potable water well (Fig. 1). After recharging the lake for several months, it became apparent that the water quality was equivalent to Wanapitei river (Sudbury's potable water supply). A lake survey indicated that the chemistry and physical characteristics had become suitable to support fish. The Ministry of Natural Resources now stocks 2,000 to 3,000 speckled trout annually, making this once dead lake a fishing area for the nearby community. Falconbridge Limited has further contributed by having seeded several hectares of land and planted trees to establish a small park. In resolving a groundwater problem for the potable water supply, a recreational benefit was also realized.

Fig. 1 FALCONBRIDGE GROUNDWATER



Research Work

The present reclamation research carried out by Falconbridge is aimed at developing an acceptable close-out strategy for the tailing and wasterock disposal sites. Conventional reclamation has not solved the continued acid seepages as shown by the following simplified reaction:

$$FeS_x + O_2 + H_2O \qquad Fe(OH)_3 + H_2SO_4$$

Initially oxidation of the iron sulphides takes place by contacting with air or by bacterial action. Acidity is produced by the oxidation of sulphide to sulphate. At pH less than 3, ferric ion becomes the major oxidant of the pyrite or pyrrhotite. The rate determining step becomes the oxidation of the Fe^{2+} (ferrous ion) which is governed by the rate of bacterial oxidation (10). To control the acid generating reaction one of the necessary ingredients must be greatly reduced or eliminated ie: iron sulphides, water, oxygen or temperature. Also inhibition of thiobacillus ferroxidans may significantly reduce the rate of acid generation to acceptable levels.

Bacterial Inhibitors

As mentioned earlier bacteria play a prominent role in leaching heavy metals by accelerating the production of acid and ferric ion. Table 2 shows the effect of bacterial leaching on ore samples over a 153 day column leach test (9).

Table 2 - Impact of T. Ferrooxidans on the leaching rate of mill feed ore

Time	pH		Fe^{3+} (mg/L)		Ni (mg/L)		Cu (mg/L)	
(days)	Control	Inoculated	Control	Inoculated	Control	Inoculated	Control	Inoculated
1	4	3.30						
2	3.89	3.34	8	12	30.0	33.8	1.32	1.99
7	2.96	2.85						
15	3.19	3.12	29	28	58.0	44	1.85	2.41
21	4.15	2.89						
28	4.11	3.57						
35	3.79	2.46	4	120	61.5	95	0.09	1.96
55	4.40	2.94						
84	4.37	2.69						
85	2.91	2.56						
86	2.77	2.52	62	400	69.0	135	0.48	6.2
93	3.55	2.77	67	196	74.0	140	0.26	6.8
108	3.47	2.63	81	231	78.0	174	0.06	
120	3.13	2.26	35	515	81.0	196	0.20	13.7
153					45.0	106	0.03	7.0

Materials tested to inhibit bacterial action included sodium lauryl sulphate and Promac, a commercial bacteriocide. Both materials showed some improvement in reducing leachates, however, more testing is required to apply shake flask lab tests to the field. Problems to be resolved are:

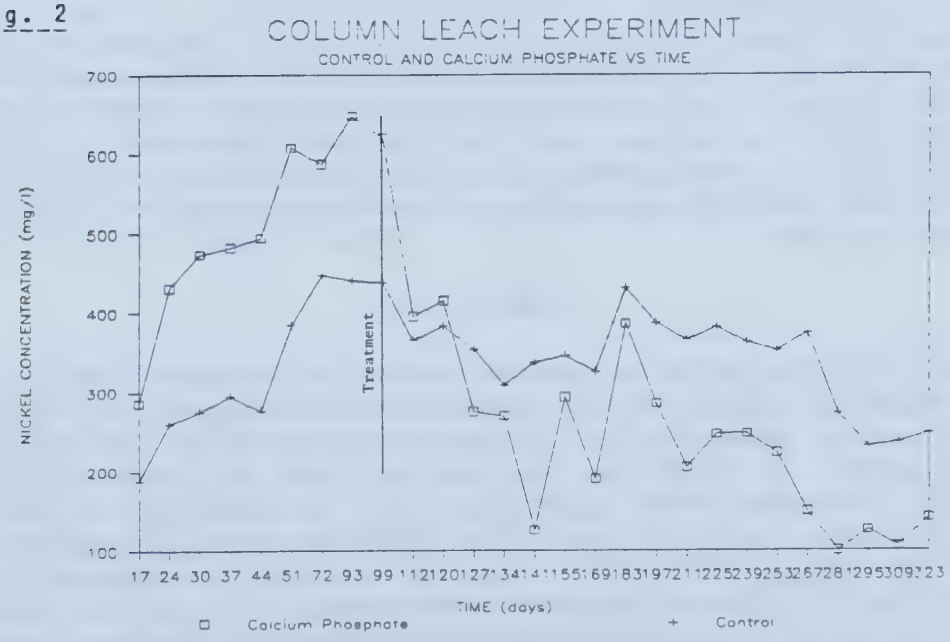
a) increasing the residence time of the treatment.
b) coating coarse rock particles uniformly.
c) preventing toxic chemicals from reaching the watershed.

Chemical Inhibitors

Various materials such as lime, calcium phosphate monobasic and apatite (calcium fluo-phosphate) are also being tested. These materials either block the ferric to ferrous oxidation reaction, result in metal phosphate precipitates, consume acid generated or produce an environment inhospitable to thiobacillus ferrooxidans. Again as with bacteriocides some improvement was noticed in the lab tests utilizing these materials. Nickel concentrations only are shown in (Fig. 2) for the $CaPO_4$ treatment.

Further test plots conducted in the field are currently being performed to determine seasonal variations and long term effectiveness of these respective treatments.

Fig. 2



Cover Materials

It would appear that the elimination of oxygen from the iron sulphides is the most practical method of preventing acid generation. For this reason, cover materials, are being tested for their ability to block oxygen. These cover materials may be subdivided into two categories: (a) dry covers (b) wet covers.

Dry Covers

The application of 2 metres of wasterock as a cover has briefly been discussed. The wasterock however being relatively porous is not considered a good oxygen barrier. To rectify this situation, sewage sludge from the community sewage plants is being deposited on top of the wasterock cover. The sewage sludge has several benefits:

a) seals the air spaces between the wasterock.
b) provides nutrients and a growth medium for natural or planted vegetation.
c) may act as a bacteriocide due to undigested sugars.
d) phosphates present may complex with the iron.

Sewage sludge has been applied to large field test areas and will be properly evaluated over the next few years.

Another waste material which may be utilized to act as an oxygen barrier is domestic garbage. A 75 sq. metre lysimeter has been constructed on the tailing area to evaluate this material as an oxygen barrier. Two metres of domestic garbage have been placed on the tailing. Oxygen profiles, methane production and seepage water quantity measurements will be made. Ideally, the methane gas will be trapped below the surface and in turn will act as an oxygen barrier.

Wet Covers

Lab and field studies by various groups, have shown that placement of sulphide tailing under water greatly reduces the oxidation rate. A lab column study by Falconbridge revealed that pyrrhotite under 30 cm. of water for one year oxidized at a rate of 0.14 Kg $S^{T}m^{-2}y^{-1}$ compared with 2.8 Kg $S^{T}m^{-2}y^{-1}$ for tailing - pyrrhotite mix in the field (2). With this in mind an attempt at constructing a wetland on top of tailing is currently being investigated. From 30 to 60 cm. of organic material was placed on top of oxidized tailing and then maintained in a flooded condition with a portable pump. During the first two months of the test considerable water quality improvements were noticed (Table 3). In just 42 days the reductions in iron, nickel and copper concentrations decreased by 77%, 99.7% and 56% respectively.

Table 3 - Flooded Organics on Tailing - Seepage Water Quality
(ppm)

Analysis	Sept. 11/86	Sept. 25/86	Oct. 10/86	Oct. 23/86
SO_4	2,450	3,425	3,645	2,560
Fe	3,320	975	1,226	766
Ni	128.2	9.4	3.23	0.37
Cu	0.045	0.01	0.05	0.02
pH	3.85	4.69	3.70	4.04

This test will be continued for three years in a flooded condition and then allowed to dry to determine if the water quality reverts back to pre-flooded condition.

An offshoot but related research project is the utilization of wetlands as a passive downstream polishing system. Considerable work has been done along these lines by groups in the United States and Canada (6). Acidity in seepage streams is reduced and dissolved metals are removed in excess of 90% by aquatic biota. Two areas at Falconbridge have demonstrated dissolved metal removal by a downstream wetland. Treated tailing effluent in the Onaping Area is improved in quality by bacteria in the lower portion of Moose Lake (3). Magnetotectic bacteria have been observed and are believed to be responsible for some of the metal removal. The Conservation Area at Falconbridge also has demonstrated a removal of heavy metals during the summer months, with nickel being reduced by 70%. Further studies are required to determine the mechanism so that it may be enhanced. This information may then be applied to construct wetlands downstream of acid seepage areas, as a means of treatment upon abandonment.

Summary

The overall company policy has been to utilize whatever resources or wastes are available to achieve an acceptable method for restoration of damaged sites and minimize the environmmental impact. Studies are currently underway to evaluate the effectiveness of wastes such as sewage or garbage in preventing acid generation in tailing and wasterock by blocking oxygen. Wetlands and bog covers are also being investigated as oxygen barriers and/or downstream metal removal systems. Research must continue to resolve these problems to develop an economical environmentally acceptable abandonment strategy for the industry to remain viable and competitive.

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REM:mh
April 30, 1987

A CONCEPTUAL MODEL OF STREAMFLOW CHEMISTRY IN AN ACID METAL-CONTAMINATED WATERSHED TREATED WITH LIMESTONE *

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ABSTRACT

Surface application of limestone to detoxify barren, acid metal-contaminated soils is standard practice in the Sudbury Regional Land Reclamation programme. Since 2600 hectares have been limed and revegetated since 1978, it is important to determine the direct and indirect impact of surface liming on groundwater and streamflow chemistry. To this end, a calibrated watershed study was initiated in 1985 in an industrially denuded basin near Sudbury, Ontario. Streamflow samples were collected from a control and a limed watershed during and after storm events, and were analyzed fro pH, and calcium and aluminum content. Results indicate that, during summer storm events, when overland flow dominates, liming raises streamflow pH and Ca content, and depresses streamflow Al content. During spring and fall storm events, and baseflow periods, liming also raises streamflow pH and calcium content and lowers aluminum content, but to a lesser degree.

INTRODUCTION

In recent years, considerable effort has been made to reclaim lakes that have become acidified through atmospheric deposition of anthropogenically derived sulphur dioxide and nitrogen oxides. The most widely used method in lake reclamation has been to add lime or limestone directly to the lake surface, thereby neutralizing the acidity and detoxifying the aluminum. However, this approach has not been fully successful, for the sudden increase in lakewater pH that immediately follows limestone treatment has an adverse effect on aquatic communities already in the lake, and continued acid loadings from the atmosphere and the surrounding watershed reacidify the lakes within a few years after treatment (Yan and Dillon, 1984; Driscoll *et al.*, 1982; Hultberg and Andersson, 1982;

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

Scheider, Adamski and Paylor, 1975). Variations to whole lake liming, including shoreline, littoral zone and streamchannel liming also have been tried to circumvent these problems, but none has been effective. In these instances, Al, Fe and humic substances carried in acid waters precipitate from solution to form coatings that inactivate the limestone (Wright, 1985; Hasselrot and Hultberg, 1984; Rosseland and Skogheim, 1984; Zurbuch, 1984; Pearson and McDonnell, 1975).

One proposed alternative to lake liming is to lime the watershed surrounding the lake so that acid inputs from the land can be neutralized prior to entering the lake (Driscoll *et al.*, 1982). In practical terms, this approach may decrease the rate of lake reacidification, resulting in reduced reclamation costs over the long term. Aquatic life might also benefit, for neutralized streams could provide a refuge for fish while sudden pH changes to lakewater would be avoided.

To date, little is known of the effects of surface limestone on streamflow chemistry. However, land reclamation efforts in the Sudbury area have increased our knowledge of lime-soil-plant dynamics. Over the last 9 years, 2,000 of 6,500 hectares of denuded, acid, metal-contaminated landscape, created by three sulphide-ore smelters emitting sulphur dioxide and particulate metals, have been reclaimed through extensive liming programs (Winterhalder, 1984). Experiments and practice have shown that liming is a necessary prerequisite to any revegetation. Liming not only increases soil pH which in turn immobilizes toxic metals such as aluminum, but it also provides a calcium source, at the same time enhancing phosphorus availability (Winterhalder, 1983a). An additional advantage to plants is that Ca improves plasma membrane integrity (Nieboer *et al.*, 1979).

In order to fill the apparent gap in our understanding of the relationship between limestone-treated soils and streamflow chemistry, a small, acid, metal-contaminated watershed was limed in the summer of 1985. The objectives of the study were to determine the effects of surface limestone application on both stormflow and groundwater chemistry, with a view to using this approach as an ameliorative treatment for acid lakes. In this paper, the Ca, Al and pH results for the storm events and for the baseflow sampling periods for the entire study period are discussed.

SITE DESCRIPTION

The watershed is located on a north-facing slope between the Falconbridge smelter to the north and the now inactive Coniston smelter to the south (Figure 1). The site covers an area of 1.38 hectares and is characterized by rock ridges and pebbly slopes. Flatter portions of the watershed contain loamy soils underlain by a hard clay that surfaces in highly eroded areas. About 27 % of the site is covered by rock outcrops with the remaining 73% covered by acid soils that have an average soil pH of 4.13 ± .18. Only 15% of the soil is covered by vegetation, with tickle grass (*Agrostis scabra*), white birch and red maple being the dominant species.

The occurrence of outcropping is such that the watershed can be divided into an upper and lower basin. These basins differ in slope and soil texture, with the flatter upper basin containing clays and clay-loam soils, and the more steep-sided lower basin containing loamy soils. For this study, the upper basin covering an area of approximately .64 hectares served as the control site, and the lower basin covering an area of .74 hectares as the experimental site. Within each basin is a well-defined streamchannel that supports sparse vegetation in some places. This channel is normally dry, except during heavy rainfalls when it gives rise to an intermittent stream.

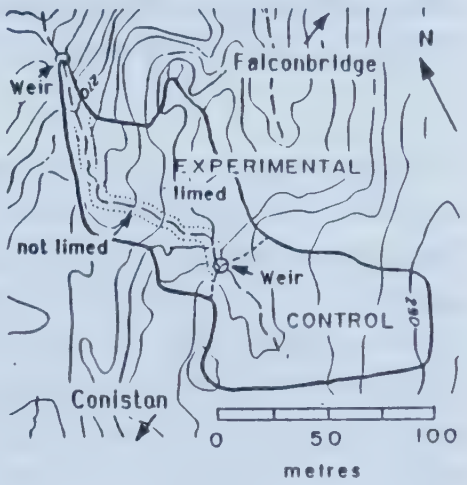

Figure 1. Topographic map of field site indicating location of control and experimental basins and weirs, and the area in the experimental basin not limed.

METHODS

The small watershed technique used in this study required that the volume and chemistry of incoming precipitation and outgoing streamflow be measured so that atmospheric and terrestrial inputs to streamflow could be identified and quantified (Bormann and Likens, 1979). To achieve this end, calibrated weirs were installed across the streamchannel at the outlets of the control and experimental basins to quantify streamflow (Figure 1), and rain gauges were set up to provide quantitative measures of precipitation. To obtain qualitative measures of streamflow, the stream was sampled at the outflows of the control and experimental basins during

two storm events prior to liming and seven storm events after liming. Qualitative samples of precipitation for each storm event were also collected in ultraclean plastic bags placed one metre above the ground.

Within 24 hours of each sampling period, sample pH and conductivity measures were taken after which time the samples were filtered and preserved with ultra-pure nitric acid for later analysis. The samples were analyzed for Al, Ca, Mg, Ni and Cu using an atomic absorption spectrophotometer. Calcium and Mg determinations were made using the flame method, while Al, Ni and Cu determinations were made using the graphite furnace. A matrix interference test for Al, Ni and Cu on samples containing high Ca levels was also performed. The results of the test indicated that there was little to no interference by Ca.

LIMING OF WATERSHED

The experimental basin was limed in early September, 1985, after 2 storm events had been sampled to provide background data for the experimental site. At that time, an area of .45 hectares was limed with 3.0 tonnes of dolomitic limestone in accordance with present land reclamation practices (Lautenbach, 1985; Winterhalder, 1983b). This amount is equivalent to an application rate of 6.7 tonnes per hectare. A 5 metre zone on each side of the streamchannel was not limed so that the effects of liming the soil surface could not be confused with those of streamchannel liming (Fig.1).

RESULTS

Before interpreting the streamflow results, it should be remembered that streamflow from the control basin flowed into and through the experimental basin, thereby reducing the full impact of limestone treatment on streamflow chemistry within the experimental site.

A Mann-Whitney U test was performed on the streamflow data to determine whether there were significant differences between control and experimental streamflow measures for each sampling period. The results of these tests, along with the mean, minimum and maximum values of the measured parameters are presented in Figures 2 to 6.

In Figure 2, comparisons between stream discharge from the control and experimental basins indicate that the hydrologic response of each basin is

similar for summer storm events but that differences occur in the fall. At this time, stream discharge from the control basin is significantly less than that from the experimental basin. A common characteristic of each basin is for stream discharge to vary considerably between storm events. This variation can be attributed to differences in rainfall intensity which determine the relative amounts of overland, subsurface and groundwater flows that are produced. A relative measure of overland flow contributions to streamflow for each storm event can be obtained by comparing the difference between maximum discharge levels to those during the baseflow periods. From such comparisons, it is evident that the greatest contributions of overland flow to streamflow have occurred in the spring and summer of 1986, with lesser contributions occurring in the fall storm events of 1985 and 1986.

The effects of liming on experimental streamflow Ca levels are clearly demonstrated in Figure 3. Prior to liming, Ca concentrations in control streamflow are either similar or significantly greater than those in experimental streamflow. However, immediately after liming, experimental streamflow levels increase significantly and remain above control levels except for the baseflow sampling period of October 14, 1985 when Ca levels in control streamflow are elevated by Ca enriched groundwater flows to the stream. Upon liming, it is also apparent that the range in experimental streamflow Ca concentrations increases, with extreme ranges occurring for storm events where overland flow is the major source of streamflow. Further comparisons between the 1985 and 1986 storm events reveal that there has been a small increase in maximum and mean Ca values in experimental streamflow over time. When the 1986 data are treated separately, a seasonal pattern appears where lowest maximum and mean values are found in the spring and fall, and highest values are observed during the summer. Another trend emerges when the 1985 and 1986 baseflow results are compared. In the control basin, baseflow levels of Ca are relatively the same for each year, but in the experimental basin baseflow levels are seen to increase in the second fall after liming.

The behaviour of experimental streamflow pH is similar to that of experimental streamflow Ca in that significant increases in pH levels occur immediately after liming and remain above those in control streamflow, again with October 14, 1985 providing the exception (Figure 4). A greater range in experimental streamflow pH values is also obseved, particularly for the post-liming storm events of 1985 when fine limestone

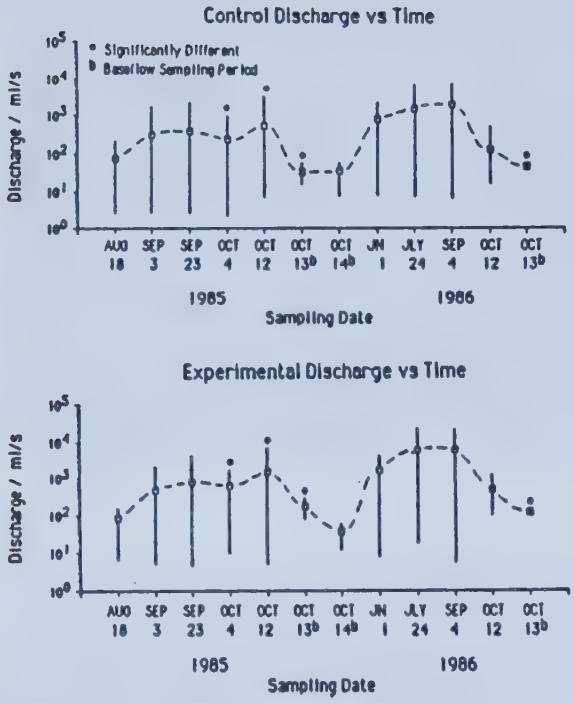
Control Discharge vs Time
Discharge / ml/s
* Significantly Different
b Baseflow Sampling Period
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date
Experimental Discharge vs Time
Discharge / ml/s
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date

Figure 2. Mean, minimum and maximum stream discharge from the control and experimental basins for each sampling date.

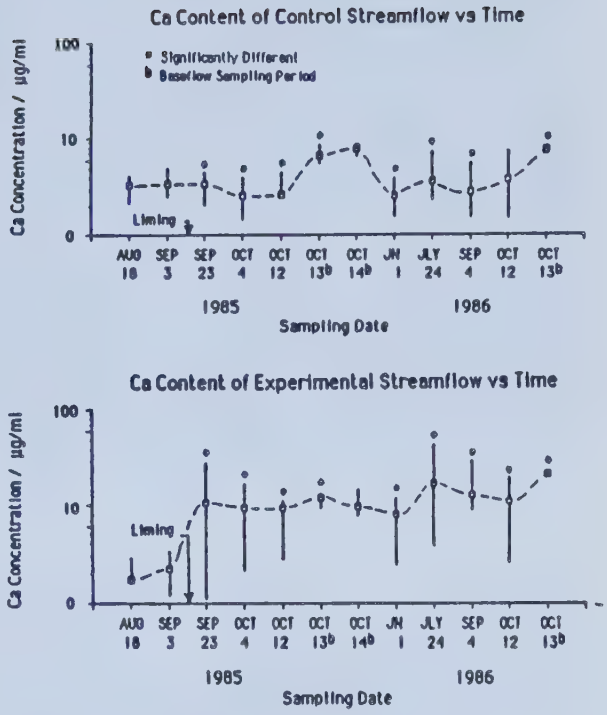
Ca Content of Control Streamflow vs Time
Ca Concentration / µg/ml
* Significantly Different
b Baseflow Sampling Period
Liming
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date
Ca Content of Experimental Streamflow vs Time
Ca Concentration / µg/ml
Liming
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date

Figure 3. Mean, minimum and maximum Ca content of control and experimental streamflow for each sampling date.

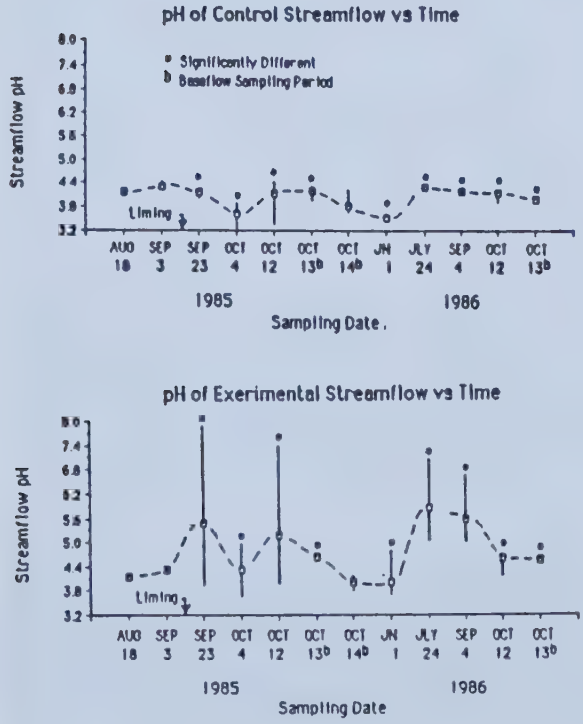
pH of Control Streamflow vs Time
Streamflow pH
* Significantly Different
b Baseflow Sampling Period
Liming
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date.
pH of Exerimental Streamflow vs Time
Streamflow pH
Liming
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date

Figure 4. Mean, minimum and maximum pH of control and experimental streamflow for each sampling date.

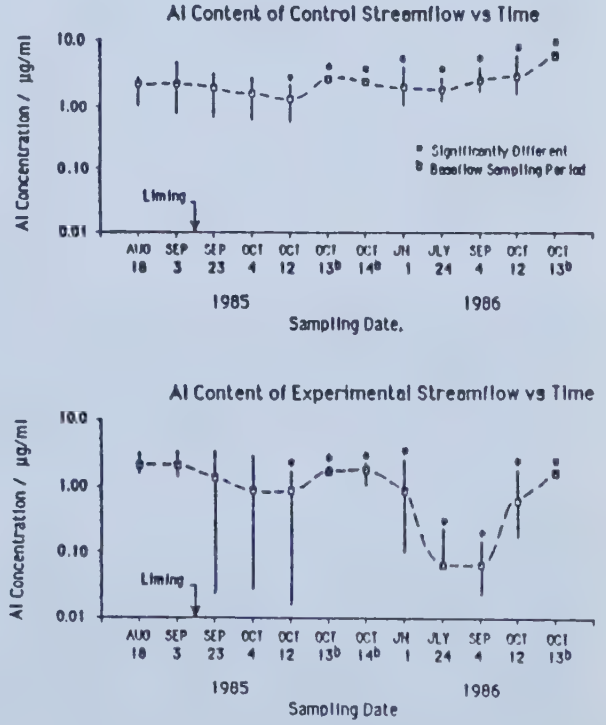
Al Content of Control Streamflow vs Time
Al Concentration / µg/ml
* Significantly Different
b Baseflow Sampling Period
Liming
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date.
Al Content of Experimental Streamflow vs Time
Al Concentration / µg/ml
Liming
AUG SEP SEP OCT OCT OCT OCT JN JLY SEP OCT OCT
18 3 23 4 12 13b 14b 1 24 4 12 13b
1985
1986
Sampling Date

Figure 5. Mean, minimum and maximum Al content of control and experimental streamflow for each sampling date.

particles were dissolved from the freshly applied limestone, and for the summer storm events of 1986. At other times, notably the baseflow periods and the spring and fall storm events of 1986, there is a decrease in the range and mean pH. In comparison, mean values of control streamflow pH do not vary greatly around an average pH of 4.10. In establishing trends in experimental streamflow pH with time, the influence of control streamflow on experimental streamflow must be taken into account. This point is highlighted by the lower mean and minimum levels of experimental and control streamflow pH that are observed for the October 4, 1985 and June 1, 1986 storm events. By excluding these events, a trend is formed where increases in pH occur when experimental streamflow is dominated by overland flow and where decreases occur when groundwater is the major source of streamflow. Further comparisons between the 1985 and 1986 baseflow sampling periods suggest that groundwater pH is increasing with time.

Unlike experimental Ca and pH levels which increase significantly upon liming, Al concentrations in experimental streamflow are similar to those in control streamflow until the third storm event after liming when they decrease significantly (Figure 5). However from the time of liming, the range in experimental streamflow Al concentrations becomes extreme but decreases in the following year. Great reductions in maximum and mean experimental streamflow Al concentrations are also observed between the post-liming storm events of 1985 and the summer storm events of 1986, with smaller reductions in mean Al concentrations occurring between the 1985 and 1986 baseflow periods and the spring and fall storm events of 1986. These results indicate that the Al content of overland flow has decreased rapidly , and that subsurface and groundwater concentrations are responding more slowly to limestone treatment.

Analysis of the results made thus far have shown that there is a general improvement in experimental streamflow Ca, pH and Al content over time. However, in order to evaluate the impacts of reduced Al and increased pH levels on aquatic life it is necessary to estimate their average total export. To accomplish this, total exports from the control basin and the entire watershed were calculated by volume and time weighting measured Al and pH values for each storm event. In the case of Al, total exports from the control basin were divided by the area of that basin and total Al exports from the experimental basin were divided by the total area of the control and experimental basins so that the Al values could be expressed as milligrams per litre per hectare. These results are contained in Figures 6 and 7.

The average export data for the experimental basin reveal that within one year after liming, toxic levels of Al are suppressed during the summer but rise to toxic levels in the spring and fall. Greatest increases in average pH also occur at this time with levels approaching the optimum value necessary for promoting a diverse aquatic community (McNeely, Neimanis and Dwyer, 1979). This pattern is not observed in control streamflow where toxic levels of Al predominate at all times and streamflow pH during the summer is more than one pH unit lower than those found in experimental streamflow.

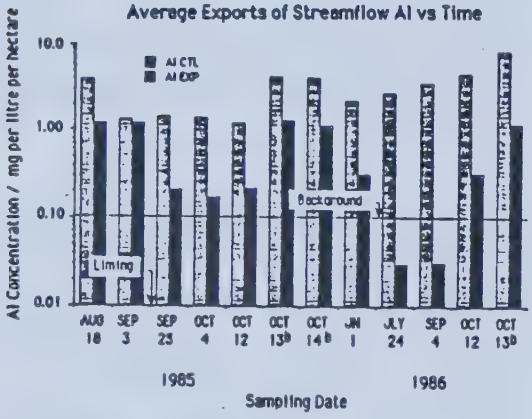

Figure 6. Comparison between time and volume weighted average exports of streamflow Al from the control and experimental basins with time.

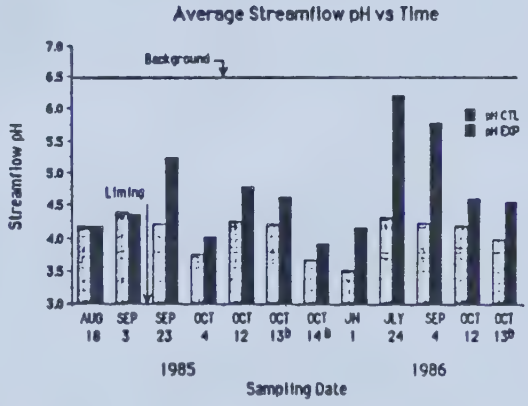

Figure 7. Comparison between time and volume weighted average streamflow pH from the control and experimental basins with time.

DISCUSSION

The seasonal and long-term trends observed in this study indicate that there are controlling factors regulating the dissolution and movement of limestone within the experimental basin. Seasonal trends can be attributed, in part, to variations in the hydrologic response of the watershed during storm events of different rainfall intensity. In this watershed, the hydrologic response is controlled by finely-textured soils and rock outcropping that restrict water infiltration into the soil, and an extensive gully system that rapidly directs overland flow to the streamchannel. Therefore, depending on the rate of rainfall, contributions of overland, subsurface and groundwater flows will vary. Streamflow chemistry will also differ as each flow is characteristically different in dissolved ion concentrations. Overland flow will be more dilute and reflect precipitation chemistry and the chemistry of soil at its surface,

and subsurface and groundwater flows will be ion-enriched and reflect soil chemistry at depth (Pinder and Jones, 1969; Newbury, Cherry and Cox, 1969).

The assumption that the hydrologic response of the watershed determines streamflow chemistry holds well for the storm events immediately following limestone application and for the summer storm events of 1986 when greatest improvements in streamflow chemistry occurred. During these times, the hydrologic response of the watershed was extreme, resulting in streamflow that was dominated by overland flow. Consequently, limestone and the products of limestone dissolution, that were carried in the overland flow, precipitated out soluble Al at the soil surface as well as those cations entering the experimental basin from the control site. Streamflow pH levels simultaneously increased as H cations were consumed in acid-base reactions. As contributions of subsurface and groundwater flows began to dominate streamflow, residual limestone swept into the streamchannel by overland flow continued to dissolve and moderate streamflow chemistry dominated by subsurface and groundwater flows. In the case of the post-liming storm events of 1985, changes in streamflow chemistry were exaggerated due to a flushout of fine limestone particles to the stream, as well as a more rapid dissolution along the unweathered surfaces of freshly applied limestone.

In contrast, the hydrologic control of streamflow chemistry cannot be used to fully explain the less impressive changes in streamflow chemistry that were prevalent in the spring and fall of 1986. As would be expected, higher levels of Al and acidity were observed in the fall event when a reduced hydrologic response produced a streamflow chemistry that was dominated by Al and acid enriched subsurface and groundwater flows. However, similar streamflow chemistry was observed for the storm event of June 1986 when major overland flow contributions to streamflow occurred. This discrepancy indicates that some other factor also controls streamflow chemistry at these times. The most probable variable is temperature, for the air temperature was less than 10^0 C during these events. This conclusion is supported by observations in the literature where limestone dissolution was found to be temperature dependent (Wright, 1985).

The apparent long-term trend in summer streamflow chemistry, dominated by overland flow, is for streamflow Al concentrations to stabilize at background levels and for streamflow pH values to fluctuate near levels that support diverse aquatic communities. The stable Al concentrations

that occur within one year of liming indicate that limestone has immobilized Al at the soil surface, whereas variations in streamflow pH suggest that average streamflow pH is dependent on the pH of rainwater. Finally, the Ca content of streamflow is increased but a definite pattern does not develop. Thus, it appears that variations in streamflow Ca between storm events are dependent on the amount of Ca washed from the soil, and the amount of limestone dissolution that occur within the streamchannel for each storm event.

Whereas an equilibrium has been achieved in summer streamflow chemistry, no equilibrium has been reached for spring and fall storm events or baseflow periods. However, there is a trend for streamflow Al levels to decrease over the year suggesting that the products of limestone dissolution are slowly entering the deeper soil profile. In the case of streamflow pH, no relative change has occurred, supporting the hypothesis that limestone dissolution is curtailed at lower temperatures, which in turn results in streamflow pH that resembles that of rainwater. Over these periods, high streamflow Ca concentrations are maintained through the transport of dissolved Ca from the soil to the stream.

CONCLUSION

Throughout the study, it has been demonstrated that the application of limestone to the soil surface has an ameliorative effect on streamflow chemistry. With time, seasonal and long-term trends were seen to develop that could be attributed to changes in the hydrologic response of the watershed and to changes in temperature. In predicting the future response of streamflow chemistry to limestone treatment, consideration must be given to changes in the hydrologic response that should occur as vegetation is re-established in the experimental basin. Assuming that revegetation will enhance water infiltration into the soil, it should be expected that overland flow will be reduced and that subsurface and groundwater flows will be increased. This in turn should lead to greater movement of limestone products into the soil profile. Thus, seasonal fluctuations in streamflow chemistry will be reduced and more rapid improvements in subsurface and groundwater chemistry will be attained. The final result should be a more stable streamflow chemistry with time.

Acknowledgements

This project was partially supported by a research grant received from the Centre in Mining and Mineral Exploration Research at Laurentian University. Special thanks goes out to J. Brault and W.E. Lautenbach of the Municipality of Sudbury, for arranging the delivery and transport of limestone to the field site.

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THE SUDBURY REGIONAL LAND RECLAMATION PROGRAM - A PLANNER'S PERSPECTIVE*

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ABSTRACT

In 1975, over 400 square kilometres of environmentally desecrated landscape existed in the Sudbury area, primarily as a result of past mining and forestry activities. As a result, a very negative national image was Sudbury's legacy which hindered future growth and development of the Region. From a planning perspective, this environmental issue had become one of the foremost critical problems facing the Region and a classic problem solving exercise of major proportions. Although much of the basic and some of the applied research had been completed, the question of how to put these findings into operation on a community wide basis remained. Crucial in addressing this question was how to organize the program and obtain the necessary resources to actually reclaim the barren landscape.

This paper indicates how these issues were addressed and some planning inferences which helped to ensure program success.

BACKGROUND

The Regional Municipality of Sudbury is located in Northeastern Ontario approximately 400 kilometres north of Toronto in Central Canada. Built into a northern landscape comprised of beautiful lakes, rocky outcrops and forested valleys, Sudbury is a vibrant urban centre of 157,000 people. It lies on the southern portion of Canada's PreCambrian Shield in a vegetation transition zone between the eastern deciduous forests of the south and coniferous forests of the north. In spite of its beautiful surroundings, a significant portion of the Regional Municipality has been disturbed by past forestry and mining industrial activities. So drastic was the environmental damage that a widespread negative image of the Sudbury community had developed. This image resulted in considerable difficulty in attracting new investment and interest in the area.

*Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987

Logging activity beginning in the early 1870's, brush fires as a result of lumbering and prospecting, and sulphur dioxide emissions from open roast smelting beds or more modern smelters at Copper Cliff, Coniston and Falconbridge, have interacted to create dramatic vegetation alteration. Following the loss of trees and other ground cover, soil erosion increased and was unchecked across much of the area. Rich soil horizons along with important nutrients were washed away. Continued acidification and increased metal toxicity of the soil from smelter emissions further added to the problem. As a result, a serious breakdown in plant-soil relationships occurred; Winterhalder (1984). By 1972, it was estimated that 104 square kilometres of the Sudbury area were completely barren and approximatey 363 square kilometres were semi-barren or moderately impacted; DeLestard (1967).

In order to improve the area's environment, large scale reductions in air pollution and major land reclamation efforts were necessary. Air quality improvements have been undertaken. However, these actions alone were not enough in many barren locations where the normal cycles of plant establishment had been broken. Here, some type of land reclamation effort was necessary to reestablish plant communities.

Most successful early reclamation attempts relied on importing soil and traditional landscaping techniques. Because of the high expense, this practice was limited to key locations, such as parks. For larger relatively flat locations such as fields or tailings areas, direct seeding techniques using agriculture methods and equipment proved feasible. Subsequently, a great deal of mining land has been reclaimed using these techniques. However, the majority of local barren lands consisted of rocky, sloping terrain with limited topsoil. Here the application of agricultural techniques was confined to limited specific locations. As a result, prior to 1978, almost all rocky terrain remained untreated.

In 1973, when Regional Government was officially established, a large percentage of the major road corridors and neighborhoods in and around the community were still barren. To help counteract this problem, the Region established a multidisciplinary technical advisory group for the purpose of revegetating barren areas. The Vegetation Enhancement Technical Advisory Committee, as it is called today, was made up of members from Laurentian University, the mining companies - Inco Limited and Falconbridge Limited, the Ontario Ministries of Environment, Natural Resources and Northern Development and Mines, the Local Conservation Authority, and local and Regional governments.

An initial action of this group was to commission further research

by K. Winterhalder of Laurentian University to determine the extent of barren areas along regional highways. This study also set up additional research test plots to determine the type of soil amendment required to support plant growth on relatively steep slopes and barren bogs. Earlier research had shown that the major limiting factors of plant growth were low pH and elevated copper and nickel levels. Soil amendments of lime and fertilizer were shown to have positive results on plant germination and growth. This latter research indicated that direct manual liming, fertilization and seeding of these areas without additional site preparation produced apparently good revegetation success.

Later in 1977, Regional Council through its Regional Plan officially set out to enhance the Region's visual quality and image by means of land reclamation efforts on disturbed lands. To accomplish this, Council committed itself to encourage research and support projects which aided this process. In spite of the fact that a great deal of community and regional concern existed regarding the appearance of the area, relatively little had actually been accomplished to change it. By late 1977, eight years of study had resulted in little actual change in the community's visual environment. Although the basic research necessary for landscape improvement was done, the major issue remaining was how to put these findings into operation on a large scale.

OPERATIONALIZING THE RESEARCH

Opportunity to operationalize the program occurred in the fall of 1977 when INCO announced the first of several major workforce reductions. At that time, representatives of the Regional Planning and Development Department and several other Departments formed a task force to determine means which would help reduce the community impact of INCO employment reductions. One of the suggestions put forward by the Planning Department was the idea to utilize student labour to help reclaim barren locations if a program could be put together. It was discovered that a Federal Program (Young Canada Works) could be utilized to fund the labour component if projects that met the program guidelines were submitted (e.g. maximum $25,000 per project).

Taking this information, B. Lautenbach and K. Winterhalder put together eight different $25,000 components for submission to the Federal Government. These submissions together formed one major land reclamation program. Following this application, the Regional Municipality of Sudbury gave a budgetary commitment of $55,000 to help cover a portion of the capital cost required for the proposed program. With the Regional commitment secured, the Ontario Ministry of Northern Affairs was approached for a matching $55,000 grant to

cover the balance of the capital cost necessary to operate the program. In the Spring of 1978 both the Federal and Ontario Governments agreed to commit their portions of the funding required, allowing the Regional Land Reclamation Program to begin.

That summer, 175 students were hired by the Regional Municipality to clean up vegetational debris and to lime, fertilize, and seed barren areas. Two highly impacted locations near the local airport and along the Trans-Canada Highway were selected for treatment on the premise that successful results would have an immediate and dramatically obvious effect. By summer's end, 115 hectares of barren area had been grassed and 200 hectares cleared of dead standing debris. The remarkable restoration of vegetation in these locations clearly demonstrated that significant landscape improvement was possible in the Region. These results successfully launched what was to become a major ongoing Regional program.

Since that first summer, the Regional Municipality has operated a major land reclamation program each year (1979-1987). Over that period numerous variations in the annual operation of the program have occurred. However, the basic conceptual framework established in 1978 has remained intact. The most significant variations have included:

1) establishing a full time coordinator to manage the day to day aspects of the program;
2) adapting the job creation aspects of the program not only to students but also to unemployed individuals and welfare recipients;
3) including tree planting as a major component of the program;
4) broadening the range of revenue sources tapped for program funding;
5) developing long range planning initiatives to ensure that long term program objectives are met; and
6) focussing on neighbourhood improvement initiatives as well as highway corridor improvements for visitors.

In all, eleven different projects have been part of the Region's land reclamation program. Five projects — grassing and greening, site improvement, tree planting, planning and mapping, and monitoring and assessment -- form the operational core. Six other projects — native seed collection, experimental transplanting, wildflower planting, reclamation research trials, and forest assessment — have been experimental or research oriented. For more information with respect to program detail, planting procedures, yearly operations or overall accomplishements, refer to the Region's summary report; Lautenbach (1985).

PLANNING PERSPECTIVES

Although putting the basic research into operation was the main planning imperative, several other important planning considerations emerged during the process. Six substantive issues are briefly discussed under appropriate subheadings. Hopefully the elements chosen and the insights gained will be beneficial and transferable to projects of a similar nature.

A. Organizing for Delivery

In order for the Region to undertake a program of this magnitude, a major organizational commitment was required. As sponsor of the program the Region had to submit funding proposals, provide project supervisors, and provide operating support services for numerous projects and hundreds of new employees. To facilitate this, the program was administered under the Region's Chief Administrative Officer with a land reclamation coordinator appointed to oversee the operation. As well, Regional employees were loaned to the program each year to assist in field supervision. In addition, most personnel, safety training, payroll, accounting, purchasing, equipment pool, and legal services are provided through existing Regional departments. As all individuals hired became temporary employees of the Region, and as a wide range of materials and supplies were required, these support services have proved most useful.

The availability of an umbrella organization or lead agency was critical in mobilizing support, focussing energy and providing legitimacy to the task. It was also useful to have an organization which was already incorporated and had the necessary Worker's Compensation Board registration, liability insurance and tax numbers.

Organization of outside contributors was also required to match assistance and timing of help with program requirements. This coordination was essential in order to maximize project benefit. This task was primarily the responsibility of the program coordinator.

B. Long Range Perspective

One of the key planning inferences which emerged after the first year of operation, was the need for a longer range perspective. Given the enormity of the task, clear targets were required if the majority of the areas' barren landscape was to be successfully reclaimed. To fill this gap, long term plans were necessary to define the scope of the problem and a possible agenda for action to

guide politicians and administrators and to inform the general public. Long term funding commitment was also critical.

To achieve this perspective, grassing and tree planting plans for the next five years were developed which identified areas for reclamation and made perscriptive recommendations. Using these plans, manpower requirements and funding needs could be calculated on an annual basis depending on revenue availability. These plans also formed the basis for selecting annual reclamation priorities.

Once the 5 year plans were completed, the Region approached the Ministry of Northern Development and Mines to secure long term core funding. On the basis of the proposed plan and the apparent need, a five year commitment was generally agreed to, with the exact dollar amounts negotiated annually. This commitment provided incentive for the Region to budget matching amounts of money each year and helped to lever funds from other sources.

C. Partnership

The value of meaningful partnership arrangements was critical to the success of the program. From the very beginning, the Region had the benefit of being able to draw on the talent, skills and resources of numerous individuals and agencies. Federal and Provincial agencies and personnel, INCO and Falconbridge, Laurentian University, various Regional Departments, the Union locals etc. all made meaningful contributions to the program. These included contributions such as: use of equipment, use or access to key staff resources, use of facilities, use of support services (e.g. accounting, personnel, legal), lobbying assistance, and financial support. These in kind contributions, made possible because of informal partnership commitment and a shared sense of vision, were critical elements in the program.

Technical advice and support were also made possible through formalized partnership. The Region's Vegetation Enhancement Technical Advisory Committee, consisting of interested individuals from business or agencies involved in some aspect of vegetation enhancement, provided Regional Council with program recommendations. The Committee also provided consulting expertise and guidance concerning numerous technical aspects of the projects undertaken. As well, the Committee provided the Region with key contacts, specialized skills, access to additional support services and research capability. Examples of this include: access to unknown Ontario Hydro funding for tree replacement that was worth $26,000; monitoring development and assistance through Laurentian University's Biology Department; use of an INCO hydro-seeder as required; and, establishment of Ministry of Natural Resources' tree planting test plots.

D. Program Flexibility

Keeping flexibility within the structure was key to meeting many program objectives. This was particularly applicable to funding arrangements which varied greatly from year to year. Flexibility allowed the Region to move from source to source as the need arose without compromising program objectives, even though each source often had unique requirements. For example, significant funding might be available for students one year, unemployed youth ages 15 to 25 the next year, and unemployed miners collecting unemployment insurance the next. By keeping delivery mechanisms flexible, the Region was able to target grant sources and adapt the program to fit the funding source requirements.

Similarly with respect to projects, the program was broad enough in scope to be able to shift yearly emphasis from grassing or tree planting toward monitoring or planning as funding requirements or capital availability dictated. Seasonal flexibility was also built into the program to allow certain aspects to be carried out during colder periods. As well, project durations were designed to meet worker requirements for Unemployment Insurance benefits or agency placement requirements through variable starting and finishing dates. By allowing for multiple objectives within the program the Region was able to shift emphasis, meet needs and make the program fit in response to emerging conditions.

E. Program Monitoring

To ensure that program objectives are being met, some type of monitoring or feedback mechanism is necessary. In this case, external monitoring was undertaken to determine how previous grassing and tree plantings were progressing. Growth parameters, survival rates and trends were investigated to indicate the need for operational adjustments or additional maintenance inputs. Monitoring of other biological parameters was also carried out by Laurentian University to assess whether functioning stable communities were occurring.

To date the results are encouraging. Although some changes have been made with respect to seed mixtures used and tree species planted, additional follow up maintenance has not been required. As well, more diversified ecological environments are developing in these areas.

Internal monitoring was also required to ensure that program objectives were achieved, that plans were followed, that key sites were reclaimed, that welfare case loads were reduced, and that the program remained labour intensive and cost effective. Subcommittees

on grassing and tree planting were established and provided input on many of these aspects. On this basis, several experimental projects - native grass seed collection, wildflower seeding, and composting projects - were curtailed as benefits did not justify the cost.

F. The Community Development Imperative

Inherent within the program was the desire for community improvement. Successful implementation of the program helped to create an atmosphere of pride within the community and helped to illustrate what can be possible when a community has a desire and determination to address current problems.

As the area became progressively greener, many residents began to improve their properties (building or landscape) near reclaimed sites. There was now concrete evidence that local improvements could make a difference. New possibilities for some vacant reclaimed sites also emerged as owners and developers viewed these properties in a new light.

However, a larger community planning inference can also be drawn from the program: The model utilized for this program can be tailored to other community projects. Projects such as waterway improvements, wildlife habitat improvement and neighbourhood development projects all have components which involve partnership, have labour intensive requirements, offer long term benefits and require community initiative to carry them out. It is hoped that the projects listed above can be undertaken within Sudbury by utilizing the lessons learned from its Land Reclamation Program.

PROGRAM SUMMARY

To date, the Region's land reclamation program has employed 1,290 students and 1,710 unemployed individuals for 45,000 work weeks. Grassing and greening, site improvement, tree planting, and monitoring and assessment projects accounted for most of this employment commitment.

Total cost of all projects undertaken between 1978 and 1986 was $13,118,000, of which $9,876,000 was for wages and benefits and $3,191,000 for equipment, transportation, materials and other capital costs necessary to carry out the work. These funds were supplied from a wide range of sources and programs, including:

1) Canada Employment and Immigration Commission:

a. Summer Canada Program/Challenge Program	$2,238,000
b. Canada Community Development Program	117,000
c. ILAP/Canada Works Program	183,000

	d. UI/IC Forestry Sector Program	35,000
	e. Mining Sector Work Program	1,184,000
	f. Canada/Ontario Employment Development Program	3,116,000
2)	Canadian Forestry Service	61,000
3)	Ontario Ministry of Northern Development & Mines	632,000
4)	Ontario Ministry of Natural Resources: Mining Sector Work Program	625,000
5)	Ontario Ministry of Labour: Canada/Ontario Employment Development Program	3,116,000
6)	Ontario Ministry of Skills Development	
	a) Ontario Youth Corp Program	348,000
	b) Futures Program	32,000
7)	Ontario Ministry of Municipal Affairs and Housing	763,000
8)	Regional Municipality of Sudbury	624,000
9)	Private Sector Donations	44,000
		$13,118,000

As a result of these initiatives, 2,600 hectares of barren landscape have been grassed and restored to a more natural setting. An additional 980 hectares have been site-improved with the removal of unsightly vegetational debris. As well, 625,000 small tree seedlings have been planted in areas previously reclaimed; Appendix A.

It is estimated that approximately 26 square kilometres of barren land has been successfully reclaimed using labour intensive techniques. More significantly, this total includes almost all of the key visual corridors along major highways and almost all of the barren sites within residential neighbourhoods. This dramatic landscape restoration is doing a great deal to change Sudbury's negative image and restore a degraded environment. These improvements, along with the Region's continuing drive to diversify its local economy, are progressively changing the image and perception of the entire area.

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APPENDIX A
LAND RECLAMATION PROGRAM ACHIEVEMENTS
1978 - 1986

Year	Amount Limed in Hectares	Amount Fertilized in Hectares	Amount Seeded in Hectares	Amount Site Improved in Hectares	Number of Trees Planted	Other Achievements As Specified
1978	114.8	114.8	114.8	206.3	-	30,000 pH and nutrient samples 365 kilograms of native seed collected 11000 trees, shrubs and plants transplanted 122 composting test plots
1979	478.6	466.6	420.2	295.9	4,250	420 hectares sampled for pH 425 kilograms of native seed collected 20,000 trees, shrubs and plants transplanted Monitoring and assessment begun.
1980	331.0	299.3	299.3	258.7	1,300	Land reclamation data assembled and computer coded. 2,000 pH samples taken 5 Year Land Reclamation Plan Developed
1981	208.0	173.4	173.4	9.8	4,600	5 Year Plan updated Monitoring and assessment records processed 29 research plots established
1982	362.4	342.4	305.2	199.2	-	Dismantled 2.4 km of abandoned trestle and improved tailings wildlife area
1983	1,084.0	934.6	935.4	-	228,080	Established 10 wildflower experimental test plots.
1984	57.7	188.4	215.9	7.5	149,350	Timber cruised 3,213 hectares Transplanted 400 trees Updated all mapping records Compiled second 5 year grazeing plan.
1985	112.0	106.0	106.0	-	154,600	Native shrub seed sources identified. Land Reclamation Summary Report 1978-1984 published
1986	24.0	30.0	30.0	-	80,300	5 year Tree Planting Plan developed Monitoring survey of trees planted 1978-1985 completed. Forest management report prepared
TOTALS	2,772.5	2,655.2	2,600.2	977.4	622,380	

TREE PLANTING ACTIVITIES OF THE SUDBURY REGIONAL LAND RECLAMATION PROGRAMME - AN EVALUATION*

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ABSTRACT

Since 1979 the Region of Sudbury Land Reclamation Programme has reclaimed more than 2500 hectares of acid, metal-contaminated land. The operational procedure consists of creating a grass-legume cover following treatment with limestone and fertilizer. Subsequently, the grassed areas are planted with tress at a low rate of stocking in an attempt to increase species diversity, provide suitable habitats for wild life and to create an aesthecically pleasing landscape. Of the 20 species used in the programme species native to central Ontario are prefered. Pines (Jack, Red and White) account for more than half of the 0.75 million trees planted since 1983. A monitoring programme has indicated that these trees have the best survival and have growth rates similar to trees in commercial regeneration sites in the area. White pine has shown a good performance in plots close to the Sudbury smelters in spite of its relative sensitivity to sulphur dioxide. Among the hardwoods Red Oak shows a good rate of survival and Black Locust (north of its natural range) increases in biomass rapidly. Although there is metal uptake into the tree tissues the levels do not appear to be toxic.

INTRODUCTION

The location of Sudbury near the southern margin of the Canadian Shield supported a transitional forest of boreal and hardwood elements. Sometimes known as the Great Lakes - St. Lawrence Forest (Rowe, 1959) the area contained extensive stands of Red and White Pine together with Yellow Birch, Sugar Maple and Red Oak. Regrowth following logging and fire supported extensive stands of White birch and Trembling Aspen (Winterhalder, 1984). Subsequent activities associated with the logging and mining industries affected over 400 square kilometres of forested landscape in the area and created a barren to semi-barren landscape(DeLestard, 1967).

Early attempts in 1969 and 1970 at rehabilitation in the Sudbury area included attempts to grow bare root and container stock on unamended barren soils had little success. (summarized by Winterhalder, 1984). However trials with bare root Jack and Red Pine in 1975 and 1976 using lime and fertilizer and in 1978 using the same species in Japanese Paper Pots (Negusanti 1978) showed excellent growth. These observations agreed with the conclusions obtained in a series of greenhouse and field trials using herbaceous species and a variety of

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

soil amendments (see Winterhalder, 1987). Subsequently, as reported by Lautenbach (1985 and 1987) the Sudbury Land Reclamation Programme was initiated under the direction of the Vegetation Enhancement Technical Advisory Committee (VETAC), that reports to the Regional Municipality of Sudbury.

PHILOSOPHY GOVERNING TREE PLANTING

Before tree planting could be successful on a large scale a herbaceous cover together with proper soil treatment was necessary. The grass-legume mixture must not be too dense so that it chokes the woody species. Nor must the herbaceous cover be sufficient to support a large population of small mammals that may damage the young trees. The grass-legume mixture provides a mulch and before the trees are fully established acts as a nutrient reservoir. However, the nutrients must become available to the trees to avoid permanent stunting. The 10 - 30% herbaceous cover achieved in programme appears suitable for adequate tree growth.

The presence of legumes should be of longterm benefit to the trees as a source of nitrogen. Indeed some of the more successful treeplots contain Birdsfoot Trefoil (Lotus corniculatus) as a dense understorey. However, the creation of woodland with an understorey of agronomic species may see unusual. Long-term monitoring has shown that the agronomic species decrease in importance over time and woody species through colonization increase in importance (see Winterhalder 1985)

This might suggest that since natural colonization of woody species is occurring so why plant trees? The major colonizers are Trembling Aspen (Populus tremuloides , willows, White Birch (Betula papyrifera) and of growing importance, Dwarf Birch (Betula pumila var. glandulifera). In time one might expect a slow colonization by climax trees, the pines, spruces and oaks. However, the monocultural problems and the visual appearance of uniform stands of these colonizers is not very appealing.

By directly introducing trees into the grassed areas total diversity could be qiuckly increased and a large number of niches made available for other components of the ecosystem. In addition one of the aims of the programme is the partial restoration of the mixed forest that was characteristic of Sudbury one hundred years ago. One established the introduced trees should act as a local source of seeds.

Mature trees in the landscape are much more intruding than a herbaceous cover. Thus it has been the intention of the Programme to follow the ideas of progressive landscape ecologists and to create semi-natural, attractive, diverse and stable bio-ecosystems (Naveh, 1982). Hence the use of extensive 'plantation' planting and very high stocking rates is vigourly avoided. Before planting site visits aid the determination of harmonious grouping of trees with the landscape, to create openings in the arrangement, to maintain sight lines and to

make the landscape appealing upon maturation of the trees. This aim is helped by the rocky terrain with small and large pockets of soil that make it difficult to completely cover the terrain with trees. Pines and Spruces have been extensively used to provide year-round greenery.

Since one of the aims is to to recreate, at least partially, the appearance of the original forest cover then the use of exotics is miminized. Black Locust (Robinia pseudoacacia) has, however, been used because of its ability to fix nitrogen and to withstand windy locations. It is often mixed with pines or Red Oak to act as a nurse tree. For autumn colour European and Japanese Larch has been used in well drained localities. There is evidence that the native Tamarack (Larix larcina) will grow satisfactory in these locations and it is intended to experiment with this species in the near future.

TREE PLANTING PROGRAMME

Before 1983 small scale planting was undertaken using a large number of species. In 1979, approximately 2500 bareroot Red and Jack Pine were planted in areas grassed in 1978. Alternate rows of trees received a peat supplement. Another 1500 paper potted Red and Jack Pine were planted at the same time in an adjacent area by the Ontario Ministry of Resources. After 5 years approximatley 70% of the trees had survived with no difference between trees supplied with or withot peat. Nor was there any statistical difference in performance between the paper-pot and bare root stock. However, the bare root stock were planted at the optimum time, in early spring. These results and those from other small scale planting led to the commencement of major operational tree planting in 1983 and subsequent years (see Figure 1). To date 887 660 trees have been planted.

The Tree Planting Subcommitte of VETAC is responsible for the selection of planting sites and tree allocation. Although a proposed tree planting plan has been drawn up (Regional Municipality of Sudbury, 1986) each site is visually inspected by the Subcommittee and the numbers of each species deliminated on 1:2000 maps for use by the planting crews.

In total 20 species have been used with the conifers predominating with 13 species and the hardwoods with 7 species. The numbers of each coniferous tree type planted is avilable in Figure 2. The most planted hardwoods have been: Black Locust 67 000. Red Oak 48 000, Silver Maple 30 000, Sugar Maple 4600, and White Ash 6000. The majority of the stock has been bareroot obtained through Ontario Ministry of Natural Resources' tree nurseries. Trees are are stored in a reefer van at 4 C until planted. All planting has occurred betwen early May and the beginning of June. Unfortunately hot and dry weather has been experienced in some years during or immediately after the planting period. In 1987 approximately 70 000 paper pot Red, White and Jack Pine will be planted in addition to the bare root stock.

TREE MONITORING AND ASSESSMENT

Monitoring of trees at selected sites is performed to evaluate survival, growth, performance and chemical composition. The results are used to refine the tree planting programme. Each monitoring site contains approximately 100 trees and each species planted is replicated at several locations across the Region of Sudbury. During the year of planting trees are assessed for survival and general health only. In subsequent years trees are individuallly identified and survival, growth by height, diameter of trunk and general health are monitored. At a few sites tree parts are sampled for chemical analysis. Full details of monitoring sites, method and results may be found in a series of tree monitoring reports produced for the Vegetation Enhancement Technical Advisory Committee (1985, 1986). The monitoring has been assisted through the use of students and their help is much appreciated.

a) Tree Survival

Figure 3 reports the mean survival of the major tree species 3 years after planting. In general the pines have the best survival rates. Black Locust is used in difficult sites but still has a good survival rate. The more sensitive hardwoods, for example maples and ash, are used in a few restricted sites with the most favourable conditions but their survival is poor. The generally shallow and dry soils of the reclaimed lands are best suited to pines and this is reflected in their best overall survival rates. The high survival of Red and Jack Pine has led to the extensive use of these two species (see Figure 2). The development of monocultures of these 2 species is not ideal and efforts are made to diversify the mixture of trees planted with or near the pines. White Cedar has a low rate of survival. In part this is due to its planting in wetland sites that are not always limed. On slopes where the reclamation treatment has been applied the survival rate of cedar increases dramatically.

b. Tree Growth

The mean annual growth for the major species is reported in Table 1.

Table 1 Mean Annual Growth of Trees on Reclaimed Land
(Measurements made 2-3 years after planting)

Species	Growth (cm) +/- sd
Jack Pine	41 +/- 15
Red Pine	34 +/- 11
White Pine	11 +/- 8
Red Oak	12 +/- 10
Black Locust	50 +/- 24
Japanese Larch	9 +/- 5

There is considerable variation from year to year. As the trees become established there is a tendency for annual growth rates to increase but variations in weather from year to year can mask this trend (see Fig. 4).

The experimental sites of Red and Jack Pine set up in 1979 have allowed growth patterns to be followed over the longer term. The cumulative growth of these species on reclaimed sites is compared to control sites (see Fig. 5 and Fig. 6). The control sites are outside Sudbury on areas that have been logged, they have similar soil properties and soil acidity but not the elevated metal levels of the Sudbury site. There is no statistical difference between the Sudbury reclaimed and reforestation sites in either species. Jack pine has the faster growth rate and is therefore a useful tree for quickly providing cover and winter greenery. However, the visual appearance of Red Pine is more appealing. These results indicate that the trees in Sudbury are performing satisfactory but need several years of growth before they can be visually appreciated.

c. Chemical Analysis

Table 2 shows the metal levels in Jack Pine needles of 3 ages taken from the control and 1979 planted site in Sudbury.

Table 3 Metal Levels in Needles of Jack Pine in Acid Soil
(ppm +/- sd; n =5)

SITE	NEEDLE AGE	Al	Cu	Ni
Sudbury	1984	324 +/- 23	8.9 +/- 2.4	16.0 +/- 3.3
"	1983	345 +/- 25	8.5 +/- 2.3	19.0 +/- 3.1
"	1982	620 +/- 42	8.1 +/- 2.1	30.0 +/- 4.4
Control	1984	234 +/- 43	2.0 +/- 1.3	3.5 +/- 1.7
"	1983	244 +/- 38	2.4 +/- 1.2	3.2 +/- 1.1
"	1982	439 +/- 56	2.7 +/- 1.3	6.3 +/- 1.3

Metal content increases with age of the needles and are elevated in the Sudbury samples. However there is little evidence of metal toxicity in the plants. Since aerial deposition of metal particulates stills occurs in the Sudbury area it is difficult to quantify the actual amount of metal on or within the needle tissue.

CONCLUSIONS

1. The procedure of planting trees into areas previously treated and grassed gives satisfactory results.
2. The tree planting programme has stressed diversity, but using the minimum number of exotic species. However, based on survival and growth information a large number of Red and Jack Pine have been used.
3. The use of White Pine, despite its alleged sensitivity to sulphur dioxide, has allowed some diversity in the use of pines. Survival of White Pine indicates that pollution control measures in the Sudbury area have been beneficial.
4. The majority of the stock planted has been bare root. This has restricted the length of the planting season. Paper pot stock could be used with advantage to extend the planting period.
5. other species of tree and shrubs have potential use in the Sudbury Programme. The present source of trees has been Ontario Ministry of

Natural Resources' nurseries and thus a restricted list of species is available. In addition, the plant material may not have originated from NE Ontario. Other species of local origin could increase the diversity and be more characteristic of the original forest ecosystem of Sudbury, A programme to collect seed of local material is at present in progress.

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Fig. 1. Total Number of Trees Planted by Year. Operational Tree Planting Commenced in 1983.

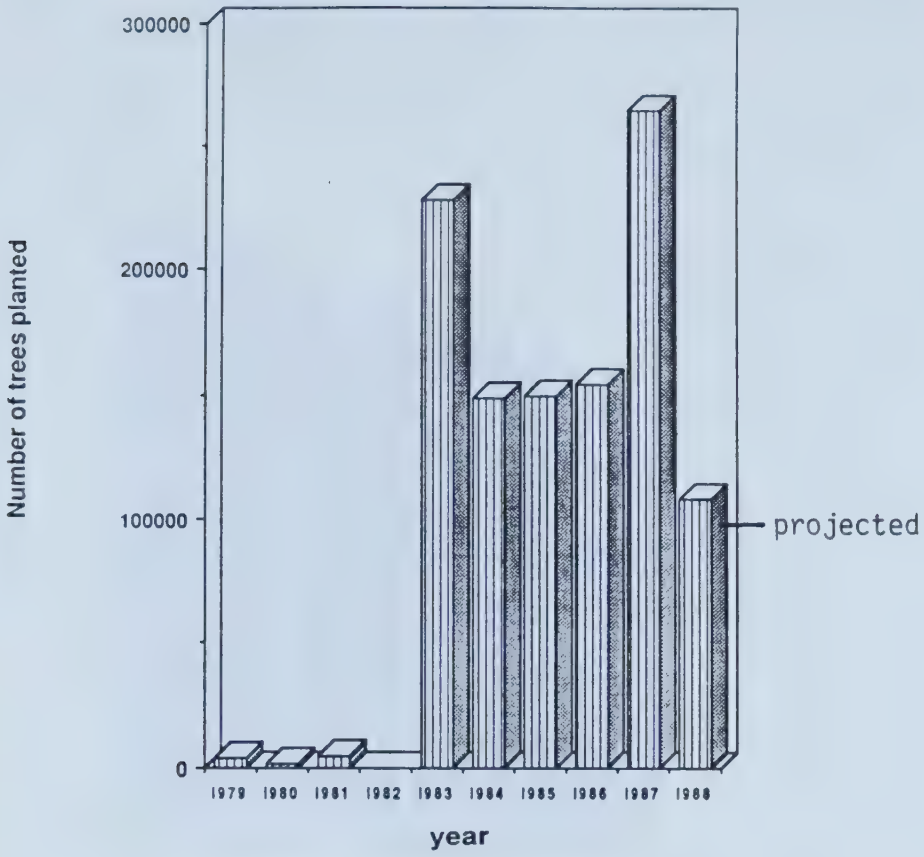


Fig. 2. Total Numbers of Conifers by Species Planted by The Sudbury Regional Land reclamation Programme. (See Appendix for Abbreviations)

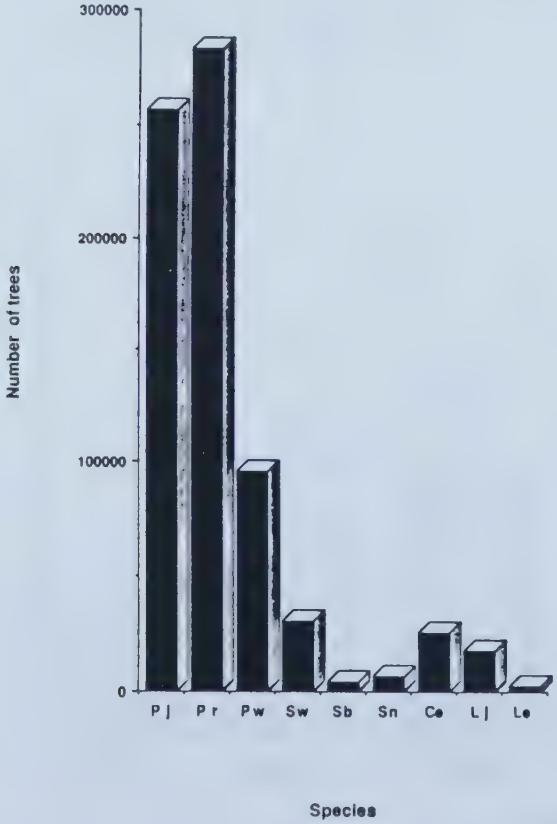


Fig. 3. Percentage Survival Rate after 3 Years of the Major Tree Species. See Appendix for Interpretation of Tree Abbreviations

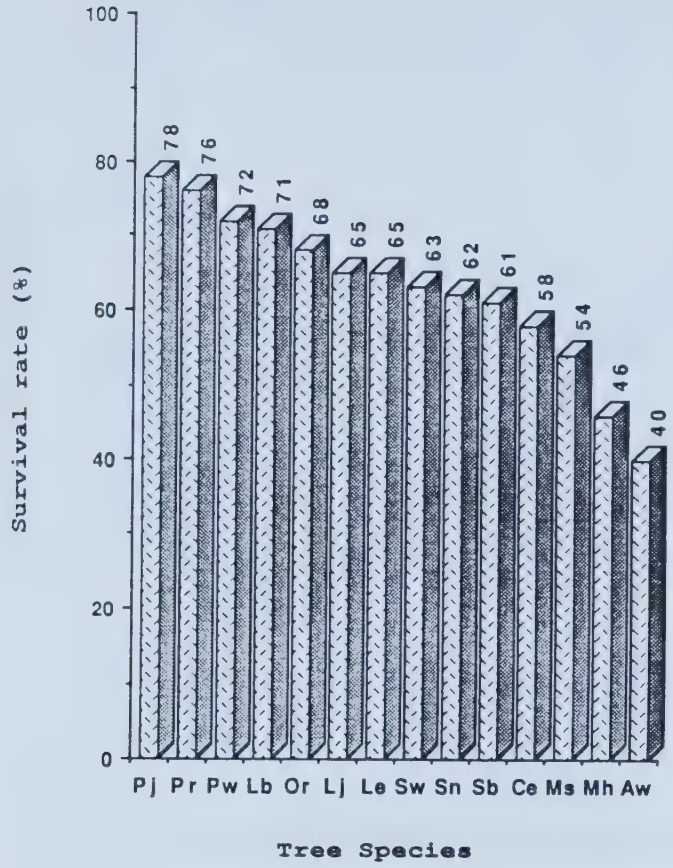


Fig. 4. Mean Annual Growth of Jack Pine planted in 1979. (n = 350). The trees are measured at the end of each growing season.

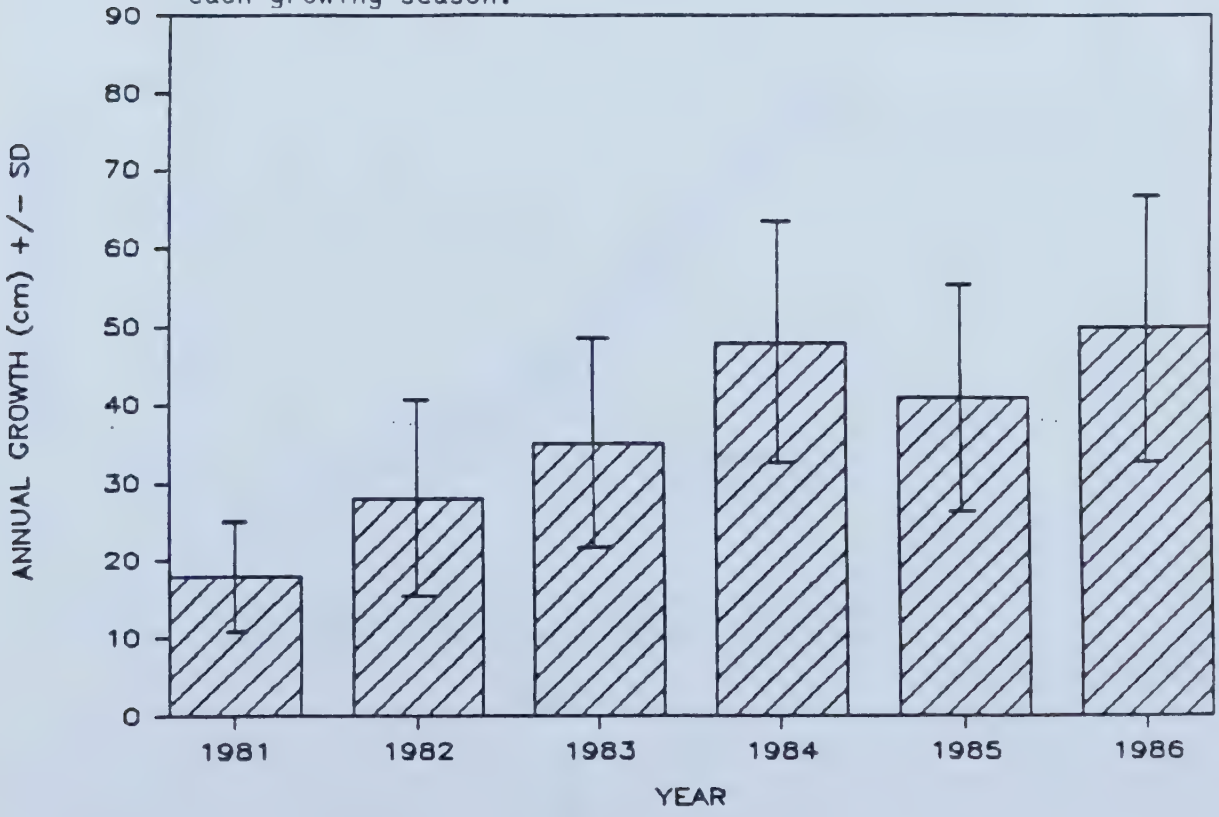


Fig. 5. Cumulative Growth of Jack Pine planted in 1979 on Reclaimed Land and on a Non-polluted Control Site. (n = 100 at both sites)

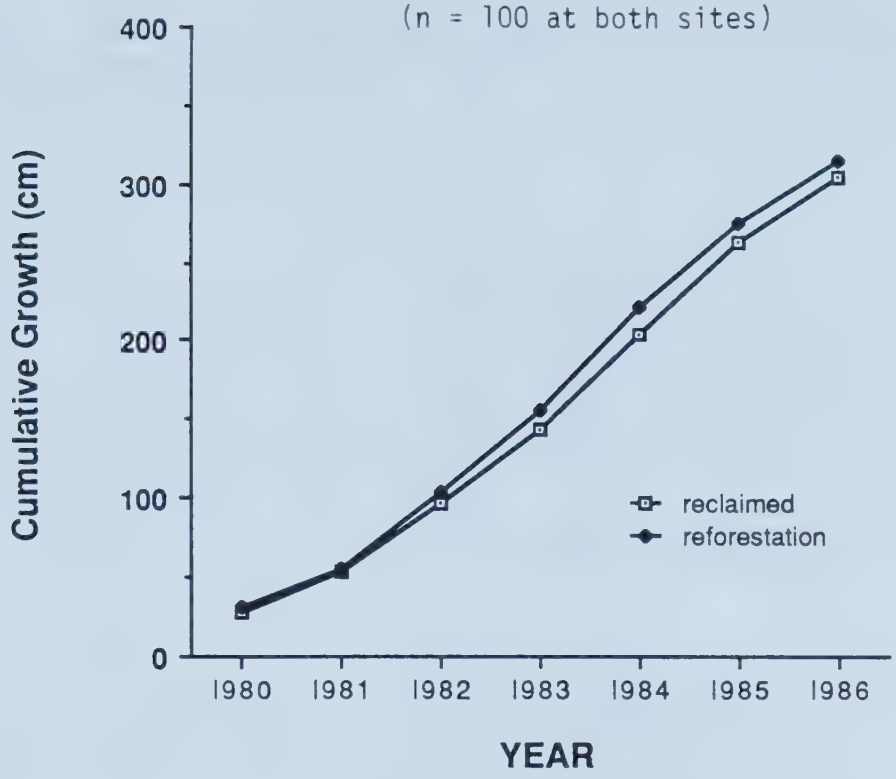
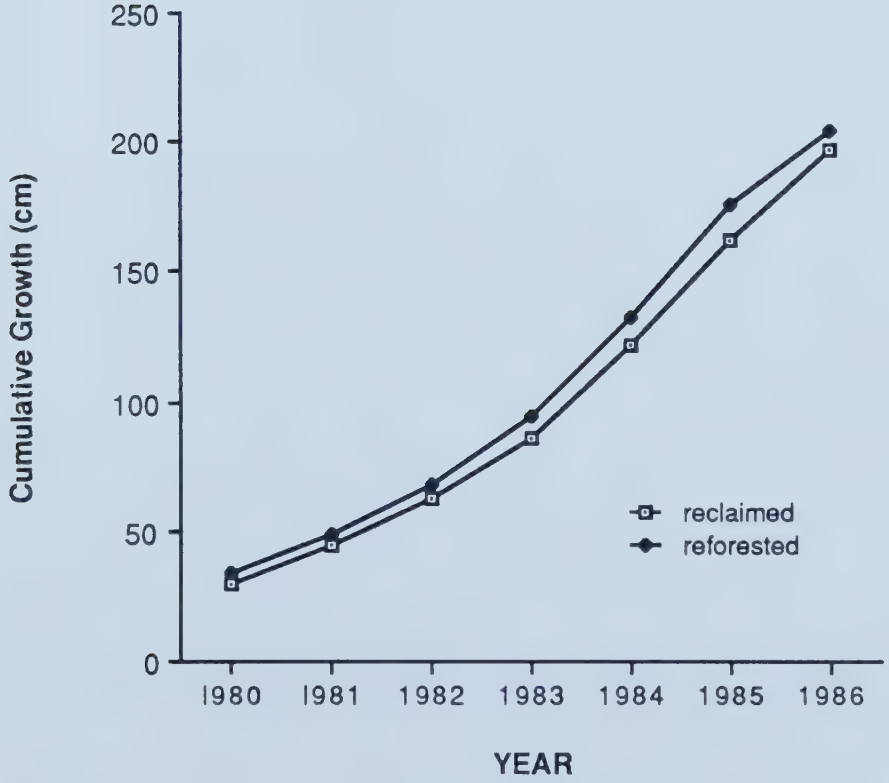


Fig. 6. Cumulative Growth of Red Pine planted in 1979 on Reclaimed Land and on a Non-polluted Control Site. (n = 100 at both sites)



APPENDIX

Common, Scientific Names and Abbreviated Name of Trees used in the Sudbury Land Reclamation Programme. * signifies species indigenous to the Sudbury area.

Common Name	Scientific Name	Abbreviation
a. Conifers		
Jack Pine*	Pinus banksiana Lamb.	Pj
Red Pine*	Pinus resinosa Ait.	Pr
White Pine (Eastern)*	Pinus strobus L.	Pw
White Spruce*	Picea glauca (Moench) Voss	Sw
Black Spruce*	Picea mariana (Mill.) B.S.P	Sb
Norway Spruce	Picea abies (L.) Karst.	Sn
White Cedar (Eastern)*	Thuja occidentalis L.	Ce
Japanese Larch	Larix	Lj
European Larch	Larix decidua Mill.	Le
Tamarack*	Larix laricina (Du Roi) K. Koch	Ta
b. hardwoods		
Red Oak*	Quercus rubra L.	Or
Black Locust*	Robinia pseudoacacia L.	Lb
Sugar (Hard) Maple*	Acer saccharum Marsh.	Mh
Silver Maple	Acer saccharinum L.	Ms
White Ash*	Fraxinus americana L.	Aw

REVEGETATION OF ALPINE DISTURBANCES*

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ABSTRACT

Revegetation trials with species, fertility, and mulch treatments were established 130 to 300 m above treeline in the Colorado Rockies. The sites on mine rock waste and on subsoil have snow cover from November into May. After seven growing seasons, the grasses Deschampsia caespitosa, Phleum alpinum, Poa alpina, and Trisetum spicatum were the dominant species on plots seeded to a mixture of native graminoids and forbs. High rates of sewage sludge (66 to 88 Mg/ha) were the most successful fertility treatments. Straw + netting, jute, or excelsior erosion blanket performed equally when evaluated on the basis of vegetative cover after seven growing seasons.

INTRODUCTION

Disturbances by road and utility line construction, mineral development, and recreation activities are continuing in alpine ecosystems in the western United States. Appropriate plant species, fertility, and cultural methods are requisites to successful revegetation on drastic land disturbances in these severe environments. This report summarizes performance of native species, fertility treatments, and mulches on disturbed soil and mine rock waste on alpine sites having winter-long snow cover. More details are in other publications (Guillaume, 1984; Guillaume et al., 1986; Berg et al. 1986).

The study sites are at the AMAX Inc. Climax Mine, Climax, Colorado. The soil site is on the upper edge of a hairgrass (Deschampsia) stand on a west-facing, 6% slope. This site is usually snow covered from November into May. The altitude is 3630 m, about 130 m above treeline. The silty clay loam soil was about 1-m deep over micaceous sandstone. The subsoil plots were prepared by removing about 25 cm of sod and topsoil to expose subsoil containing an estimated 20% coarse fragments, 1.3% organic matter, and testing low in NO_3-N, P, and K.

The mine rock waste site is located on a nearly level bench formed by bulldozer leveling of open-pit mine waste. The site is bordered on the south and east by alpine fellfield that slopes steeply upward creating a site that has winter snow cover which persists later in the spring than on the soil site. The altitude of the mine rock waste site is 3840 m, about 330 m above treeline. The mine rock waste

*Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

contains about 75% coarse fragments ranging upward to 1-m diameter. The texture of the soil size material is sandy loam which tested low in organic matter and NO_3-N, but adequate in P and K.

PERFORMANCE OF NATIVE SPECIES IN MONOCULTURES

Seed was collected from native stands near the Climax Mine and in Rocky Mountain National Park in the late summer and early fall of 1978 on the basis of observations on species invading alpine disturbances and abundance of seed. Hand collection took about 60 man-days to collect 3.9 kg of pure live seed. Germination and seeds/unit mass were determined and reported by Guillaume (1984).

Monocultures were seeded only on topsoil. Individual plots are 0.45 x 6 m with the seed planted in 3 rows 15 cm apart on October 14, 1978. The area was fertilized, furrowed, seeded, raked lightly, straw mulched at the rate of 4.4 Mg/ha, and covered with plastic netting. Establishment and persistence was good for most of the native species as shown by relatively high frequencies in 1980 and 1985 (Table 1). However, the growth rate was slow. Ground cover produced after two growing seasons averaged only 7% and 4% for graminoids and forbs, respectively (Table 1). By 1985, ground cover had increased substantially for most of the graminoids (Table 1). The forbs, Antennaria rosea, Polygonum bistortoides, and Potentilla diversifolia, had significant increases in ground cover from 1980 to 1985.

PERFORMANCE OF GRASSES AND FORBS SEEDED IN MIXTURES

A mixture of native species (Table 2) was seeded on subsoil and mine rock waste in the fall of 1978 at the rate of 8.6 kg pls/ha. Prior to seeding the plots were fertilized with 18-46-0 at 336 Kg/ha or with sewage sludge at 22 Mg/ha (subsoil) or 66 Mg/ha (mine rock waste). The plots were mulched with straw held down with plastic netting.

Frequencies of four grasses were much greater than the frequencies of the other species (Table 2). Among these four grasses, Deschampsia caespitosa did not have a change in frequency from 1980 to 1985, Phleum alpinum and Poa alpina increased in frequency, and Trisetum spicatum increased in frequency on the subsoil. The increases in frequency are probably a reflection of both: 1) our inability to identify very small seedlings in 1980, and 2) an increase in number of plants due to natural seeding. In 1985 numerous small grass seedlings were present in these plots. Two grasses (Poa glauca, and P. reflexa) not intentionally seeded, but present by invasion or inadvertently included in seed collected, were found on the plots (Table 2).

Frequency of forbs was extremely low in relation to frequency of the grasses (Table 2). Some of the forbs performed relatively well in monocultures on the topsoil (Table 1) but apparently could not compete with grasses when seeded in mixtures on subsoil or rock waste.

Seed harvested with a combine in September 1979 from the surrounding alpine meadow and seeded in 1979 into subsoil plots resulted in frequencies of greater than 10% for each of 8 species by 1985 (Table 3). Four of these species, Deschampsia caespitosa, Phleum alpinum, Poa alpina, and Trisetum spicatum also performed well in the plantings of hand-harvested native seed mixtures (Table 2). Other species from the combine seed harvest with a frequency of greater than 10% were Agropyron latiglume, Carex spp., Poa glauca, and Achillea millefolium.

The performance of Achillea millefolium is of particular interest. This forb was not seeded in other alpine plots, however, it was seeded on mine rock waste in the upper subalpine zone (Guillaume, 1984) where its frequency was high in 1985 (W. A. Berg, unpublished data).

Thus, the planting of the native seed mixture harvested with a combine resulted in a considerably greater number of species contributing to the revegetation population (Table 3) than did the seed mixture made up of hand-collected natives (Table 2). The amount of vegetative ground cover (70%) in 1985 on the subsoil plots planted with the combine-harvested seed was not significantly different from the vegetative cover (76%) on plots planted to the hand-collected native seed mixture on plots treated with comparable sewage sludge rates (88 Mg/ha).

Overall, the grasses, Deschampsia caespitosa, Phleum alpinum, Poa alpina, and Trisetum spicatum performed well in these alpine seedings as they did in trials reported by Brown and Johnson (1979). Performance of the forbs in the grass-forb seed mixtures was disappointing with the exception of Achillea millefolium which was included in only one of the four alpine seedings reported here. Among the other forbs tested, Antennaria rosea, Polygonum bistortoides, and Potentilla diversifolia may hold some promise for seeding into alpine disturbances. The latter 3 species were ranked high as colonizers on alpine disturbances in Montana (Chambers et al. 1984).

EFFECT OF FERTILITY TREATMENTS

Fertility treatments included chemical fertilizers, sewage sludge, and 7.5 cm of soil cover (Guillaume, 1984). The chemical fertilizer treatment reported on here is diammonium phosphate (18-46-0) applied at the rate of 336 kg/ha prior to seeding in October 1978. Sewage sludge rates ranged from 11 to 88 Mg/ha. The sewage sludge was dry anaerobically digested primary sludge from the Denver Metro northside plant. The sludge contained 13% organic matter which is low for this type of sludge (personal communication B. R. Sabey, Agronomy Dept., Colorado State Univ.) Woodchips at the rate of 44 Mg/ha were added to sewage sludge treatments applied to the mine rock waste. The purpose of the woodchips was to immobilize and thus conserve nitrogen from the sludge.

The seed mixture shown in Table 2 was seeded on the plots after chemical fertilizer or sewage sludge treatments were mixed into the

subsoil or mine rock waste. The plots were mulched with straw held in place with plastic netting.

The second growing season (1980) after seeding, vegetative cover averaged only 5 to 8% on the subsoil site with no significant differences among fertility treatments (Guillaume 1984). In the seventh growing season (1985) vegetative cover was 2 to 2.5 times greater on the high-rate sewage sludge treatments than on the chemical fertilizer treatment (Table 4). Our 1985 observations were that the native grasses were larger and a darker green color on the high-rate sewage sludge treatments than on the chemical fertilizer treatment. The darker green color indicates that the major benefit received from the high-rate sewage sludge is a greater supply of plant-available nitrogen. The lower rates of sewage sludge generally produced vegetative cover in amounts similar to or slightly greater than on the chemical fertilizer treatment (Table 4).

The treatment of 7.5 cm of stockpiled topsoil applied over the mine rock waste in 1978 resulted in vegetative cover of 15+2 (std error)% in 1985. With the topsoil treatment + 336 kg/ha of 18-46-0 applied in 1978 the vegetative cover was 22+1% in 1985. Thus, treatment of rock waste with approximately 1100 Mg/ha of stockpiled soil appears to be little more effective than treatment with chemical fertilizers (Table 4). This result is surprising and may relate to the quality of the cover soil.

EFFECT OF MULCHES

Mulch treatments applied to the subsoil site after seeding in October 1978 included: 1) 4.4 Mg/ha wheat straw held in place with plastic netting (Conwed), 2) jute, 3) excelsior erosion blanket, 4) 44 Mg/ha woodchips, 5) 4.4 Mg/ha wheat straw + plastic netting, net removed in 1979. Treatment 5 was applied to simulate a straw mulch held in place with a tackifier. Mulch treatments applied to the mine rock waste were the same as above except treatment 5 where no-mulch was applied.

Type of mulch applied on subsoil had no significant effect on amount of vegetative cover produced during the seventh growing season (Table 5). A no-mulch treatment was not attempted on the subsoil because of the high potential for erosion of the silty clay loam soil onto other treatments. Rill erosion was obvious in 1985 on subsoil plots mulched with woodchips. Erosion was not evident in other mulch treatments.

A no-mulch treatment was included on the rock waste since there was no erosion potential on this coarse material. Vegetative cover on the rock waste in August of the seventh growing season was similar among the mulches, and between all mulches and the no-mulch treatment except for the jute (Table 5).

Two years after mulch application, Guillaume (1984) noted little degradation of the jute, excelsior or woodchip mulches. Straw was more

clumped under the net in 1980 and ground cover by straw was reduced from about 90% in 1978 to 75% in 1980.

Seven years after application most of the mulch materials had decomposed. No straw remained, but the plastic netting used to hold the straw was intact, although brittle. An estimated 10 to 20% of the jute remained as isolated strands. No excelsior remained except under rocks (20-30 cm diameter) placed to hold the mat down. The green plastic netting holding the excelsior had disintegrated to pieces no larger than 1 cm. A few woodchips were present, largely in clumps, and made up no more than 5% ground cover.

CONCLUSIONS

A number of native species can be established on alpine disturbances that have continuous winter snow cover. However, seven years after seeding into drastic disturbances (subsoil and mine rock waste), four native grasses dominated plots seeded to a mixture of native species.

These native grasses, Deschampsia caespitosa, Phleum alpinum, Poa alpina and Trisetum spicatum also performed well in other alpine seedings (Brown and Jackson, 1979; Walker and Harrison, 1986) and are common colonizers on alpine and upper subalpine disturbed sites having winter snow cover. Numerous grass seedlings were observed during the seventh growing season in the subsoil and mine rock waste seeded to natives. Since the utility of these native grasses has been demonstrated, we suggest agencies or companies anticipating reseeding alpine disturbances having winter-long snow cover contract for seed of these species in advance of the need. The supply might be by commercial seed production techniques, or possibly, harvest of native stands by mechanical seed strippers (Dewald and Beisel, 1983). Species diversity in plots seeded with the combine-harvested natives adds interest to harvest of native stands.

High-rates of sewage sludge (66 to 88 Mg/ha) were the only fertility treatments used in this study which offer the potential for a no or minimum maintenance approach to alpine revegetation on infertile soil materials. At these sewage sludge rates enough vegetative cover was produced after seven growing seasons to control erosion and ameliorate the visual effect of disturbance. However even at the highest sewage sludge rate, dry matter production (about 900 kg/ha) on the subsoil during the seventh growing season was estimated to be about half of that produced on the adjacent native Deschampsia meadow. Slow growth in the alpine environment was shown by the production of 8% or less vegetative cover after two seasons even with high-rate sewage sludge treatments.

Mulch is probably a necessity on many alpine revegetation sites because of the high erosion potential. Straw + netting, Jute, or excelsior performed equally in this study when evaluated on the basis of vegetative cover after seven growing seasons. On the mine rock waste, which was very coarse textured, the advantage of mulch in

producing vegetative cover was not conclusively shown.

Potential users of information presented in this report are cautioned that the studies were on alpine disturbances with winter-long snow cover. Windswept alpine sites would present much more difficult revegetation problems.

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Table 1. Seeding rate, vegetative cover, and frequency of native species planted as monocultures in topsoil.

	Viable seed planted in 1978	Vegetative Ground Cover			Frequency within 10x10 cm quadrats		
		1980	1985		1980	1985	
	-- number/m^2-	---- % ----			---- % ----		
Graminoids							
Agropyron latiglume	300	8	20	ns	66	54	ns
Carex atrata	1400	0	1		1	9	
Carex ebenea	2900	1	22	*	40	47	ns
Deschampsia caespitosa	4700	9	56	ns	81	77	ns
Festuca thurberi	2200	3	16	*	87	51	†
Phleum alpinum	2900	10	41	*	78	80	ns
Poa alpina	10600	17	59	*	83	94	ns
Poa glauca	1500	8	39	*	53	69	†
Trisetum spicatum	3000	11	28	ns	83	92	ns
Forbs							
Androsace septentrionalis	12500	7	1		79	4	†
Antennaria rosea	8300	8	28	*	57	76	†
Artemisia arctica	27500	4	12	ns	33	41	ns
Castilleja spp.	5700	0	1		1	1	
Geum rossi	1600	1	10	ns	40	48	ns
Hymenoxys grandiflora	2600	1	8		52	29	†
Oxyria digyna	1500	10	9	ns	63	49	ns
Polemonium viscosum	800	1	4		39	31	ns
Polygonum bistortoides	unknown	3	11	*	23	46	†
Potentilla diversifolia	6900	6	44	*	63	72	ns
Rumex spp.	1900	2	7		52	27	†

*Ground cover is significantly different (P=<0.05) between years by F test; when ground cover <10% for both years F not calculated.
†frequency is significantly different (P<0.05) between years by Chi-square test; when frequency<10% for both values Chi-square not calculated.

Table 2. Native species frequency in 1980 and 1985 on subsoil and rock waste sites seeded to a mixture of native species in 1978.

	Viable Seed Planted in 1978	Frequency				
		Subsoil 10x10 cm quadrats			Rock Waste 20x20 cm quadrats	
		1980	1985		1980	1985
	number/m^2	%			%	
Graminoids						
Agropyron latiglume	10	2	3		4	<1
Carex spp.	100	3	2		2	8
Deschampsia caespitosa	280	15	15	ns	23	23 ns
Festuca thurberi	60	<1	<1		0	4
Phleum alpinum	180	9	16	†	16	32 †
Poa alpina	240	16	33	†	20	53 †
Poa glauca	0	0	<1		0	6
Poa reflexa	0	0	1		0	38 †
Trisetum spicatum	120	13	21	†	20	22 ns
Forbs						
Androsace septentrionalis	8	1	<1		0	0
Artemisia arctica	30	1	<1		0	<1
Castilleja spp.	110	0	<1		0	<1
Geum rossi	12	0	<1		<1	0
Hymenoxys grandiflora	6	0	0		0	0
Polemonium viscosum	30	<1	<1		2	2
Potentilla diversifolia	110	<1	1		<1	1
Rumex spp.	50	3	1		1	<1

†frequency is sign. different ($P<0.05$) between years within a site by Chi-square test; when frequency <10% for both years Chi-square was not calculated.

Table 3. Frequency of species in 1985 on subsoil seeded in 1979 with combine-harvested seed from adjacent alpine meadow.

	Frequency within 10x10 cm quadrat
	%
Graminoids	
Agropyron latiglume	20
Carex spp.	17
Deschampsia caespitosa	27
Festuca spp.	1
Phleum alpinum	23
Poa alpina	26
Poa glauca	23
Poa reflexa	6
Trisetum spicatum	15
Forbs	
Achillea millefolium	13
Castilla spp.	<1
Epilobium angustifolium	<1
Geum rossi	<1
Lepidium spp.	<1
Polygonum bistortoides	1
Potentilla diversifolia	5
Rumex spp.	2

Table 4. Effect of Fertility Treatments on Vegetative Cover on Subsoil or Mine Rock Waste Sites seven years after application.

Site	Fertility Treatment					
		Sewage Sludge Mg/ha				
	336 kg/ha 18-46-0	11	22	44	66	88
	%					
Subsoil	28 c‡	35 c	38 c	65 b	-	76 a
Mine Rock Waste †	17 c	-	22 bc	31 ab	42 a	-

† On mine rock waste all sewage sludge rates also received 44 Mg woodchips/ha

‡ Means within a row followed by a common letter are not significantly (P=0.05) different. Do not use for comparison of means within column.

- Treatment not in study.

Table 5. Vegetative cover of native species in 1985 on subsoil or mine rock waste as affected by mulches applied after seeding in 1978.

Mulch	Site	
	Subsoil†	Mine Rock Waste‡
	%	
Straw + net	34 a§	23 ab
Jute	37 a	28 a
Excelsior	33 a	23 ab
Woodchips	31 a	25 ab
Straw - net (1979)	37 a	-
No mulch	-	19 b

†Mean of the chemical fertilizer plus 22 Mg/ha sewage sludge fertility treatments.
‡Mean of the chemical fertilizer plus 66 Mg/ha sewage sludge fertility treatments.
-Treatment not in study.
§Means within a site followed by a common letter are not significantly (P=0.05) different.

SLOPE STABILIZATION - PARLIAMENTARY PRECINCT, OTTAWA*

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ABSTRACT

A three phased study, consisting of problem identification, preparation of a master plan for rehabilitation and implementation of the proposed plan, has been completed for the north slopes of the Parliamentary Precinct, Ottawa. Steep slopes in excess of 100 percent, shallow soils and a loss of vegetative cover, have led to excessive soil erosion, damage to slope structures and related public safety problems and low aesthetic quality.

A combination of bioengineering techniques used in connjunction with planting native vegetation to enhance species diversity were used to stabilize the slopes. Approximately 160,000 stems of overstory and understory vegetation were planted on 4•3 ha. over a five year period.

BACKGROUND

In 1980 Ecological Services For Planning Ltd. was authorized to investigate vegetation and soil factors affecting the stability of the slopes located behind the Parliament Buildings. These north-facing slopes along the Ottawa River have shown signs of instability in the form of bedrock weathering, talus formation, soil creep and surface soil erosion, together with a loss of vegetative cover, damages to slope structures and related hazards to public safety. Problems on the slopes include:

- A history of human disturbance on the slopes.
- Long term erosion and maintenance problems.
  - Deterioration of slope structures; walls, stairs and walkways
  - Surface erosion features, soil creep, talus accumulation, rill erosion
  - Loss of vegetation; death of hundreds of elms due to Dutch Elm Disease
  - Unsightly appearance of the slopes; garbage, debris, fallen structures, sparse vegetative cover.

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*Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

The first phase of the study provided a general inventory and mapping of slope conditions, with some recommendations regarding site amelioration. Phase II gave a detailed analysis of slope conditions, with onsite mapping of soils, surface erosion features, tree, shrub and ground cover, and pedestrian circulation patterns on the slopes. The inventory provided the background data for input to the preparation of a master plan for stabilization and rehabilitation of the slopes.

The goals for development of the master plan were:

- o To outline slope conditions and problem areas.
- o To determine causes of slope erosion problems.
- o To provide alternatives for slope rehabilitation.
- o To give detailed solutions for management with vegetation.

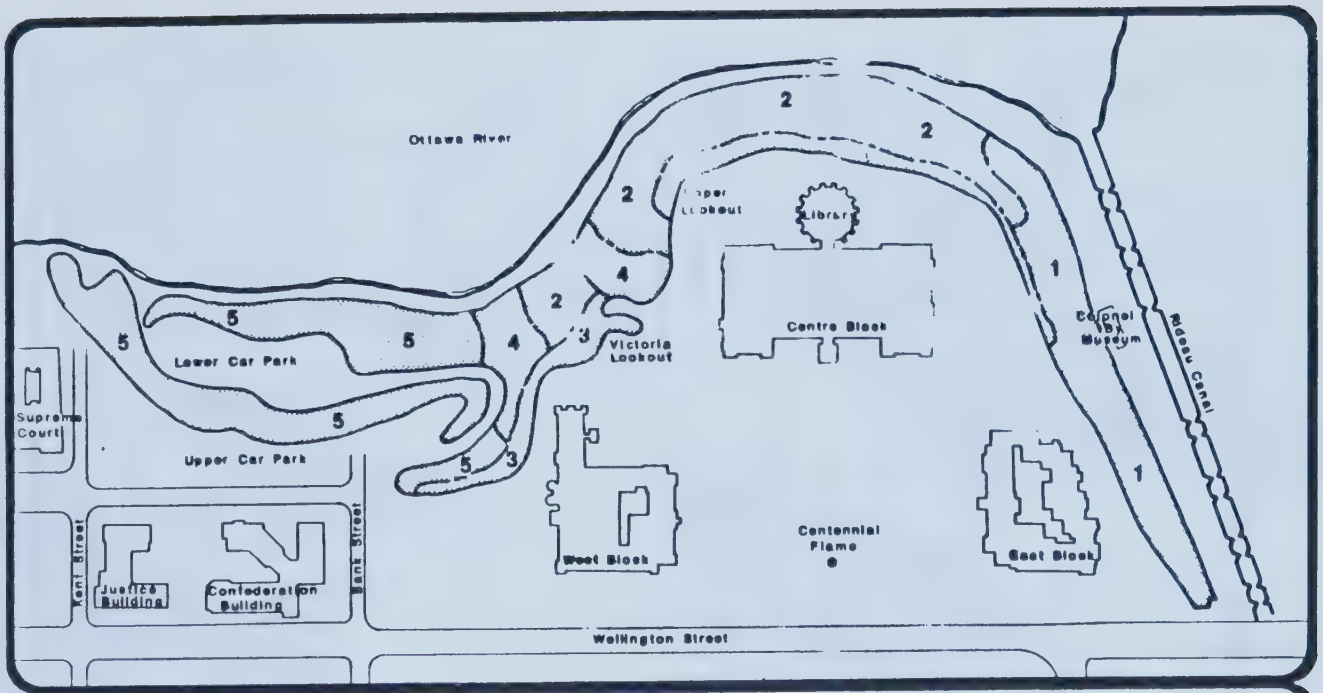
The final master plan for slope rehabilitation contained detailed recommendations for slope stabilization with native vegetation, using specialized methods designed specifically for steep and unstable slopes. Construction was implemented over a five year period beginning in the fall of 1983.

This paper provides a summary of the Parliament Hill Slope Rehabilitation Project from its initial stages of investigation to the final recommended slope management techniques and construction procedures. It includes a brief summary of slope problems, together with plant establishment techniques.

SUMMARY OF SLOPE PROBLEMS

The entire slope was mapped on the basis of two types of vegetative management units: a ground based management (ground cover and rehabilitation works) and an overstory vegetation management unit. Ground based management units were based on soil conditions, slope angles, general overstory conditions and ground cover groupings. Overstory management units were based upon tree density, shrub density and slope angle. The actual criteria for the selection of the management units is detailed in the Parliament Hill Slope Rehabilitation Final Technical Report (1983).

The management units were used as the basis for developing the planting prescriptions and the remedial works for the plant establishment techniques. For the purposes of scheduling and preparation of construction tendering documents, the overstory and ground based management units were combined into five simpler units called problem sectors (Figure 1). The Problem Sectors are defined on the basis of uniformity in relation to the type of problem, the underlying causes and the general solutions proposed to deal with the problems.



PARLIAMENT HILL SLOPE REHABILITATION

PROBLEM SECTOR	PROBLEM SUMMARY
1	Dense overstory, poor ground cover, surface erosion
2	Lack of species diversity and vegetation cover, talus soils
3	Old, top-heavy shrubs and shallow soils
4	Coarse rubble soils, poor vegetation cover
5	Erosion pathways, locally dense overstory

PROBLEM SECTORS

NORTH

Figure 1

Ecological Services for Planning Ltd

PUBLIC WORKS CANADA
TRAVAUX PUBLICS CANADA

0 20 50 100 metres

Each Problem Sector consists of a combination of management units. A brief summary of the general problems found in each Problem Sector are outlined in Table 1.

TABLE 1 - GENERAL SLOPE PROBLEMS

VEGETATION	SOIL	OTHERS
-Lack of species diversity. -Lack of regeneration. -Lack of litter accumulation. -Lack of overstory in some areas. -Lack of groundcover in some areas. -Potential of leaning stems and trunks to topple & pull up root mass. -Potential of woody plant roots on rock faces to loosen rock blocks.	-Surface sheet erosion. -Rill & gully erosion. -Talus instability. -Potential rock failure on exposed faces -Deep mass movement in certain areas (solution requires major engineering works)	-Pedestrian movement up & down slopes on specific routes -Safety hazards due to periodic failures of Lover's Walk with heavy masonry pieces falling down slope -Attracting nuisance of remaining Lover's Walk and associated stairways-potential injury due to unauthorized use. -Unattractive appearance of debris and non-vegetated areas. -Drainage discharged down slope from above.

Problem Sector 1 is located along the east-facing slopes leading down to the Rideau Canal. The problem that exists in this area is that only two tree species dominanted the canopy, namely, Norway Maple (Acer platinoides) and Manitoba Maple (A. negundo), both of which are introduced exotic species for this area. These species characteristically produce large crowns that allow little light to reach the ground surface. Hence, there is limited ground cover vegetation and tree regeneration established under the canopy. As a result, the slopes are exposed to erosive forces, particularly in spring and autumn when there are no leaves on the trees. Surface sheet erosion was prevalent throughout the sector.

To correct the problems, the canopy was gradually thinned of the overstory trees to allow light to penetrate to the ground surface to facilitate ground cover growth. The area was subsequently seeded and planted with appropriate trees, shrubs, and ground covers. Figure 2 illustrates a before and after scenario for Problem Sector 1.

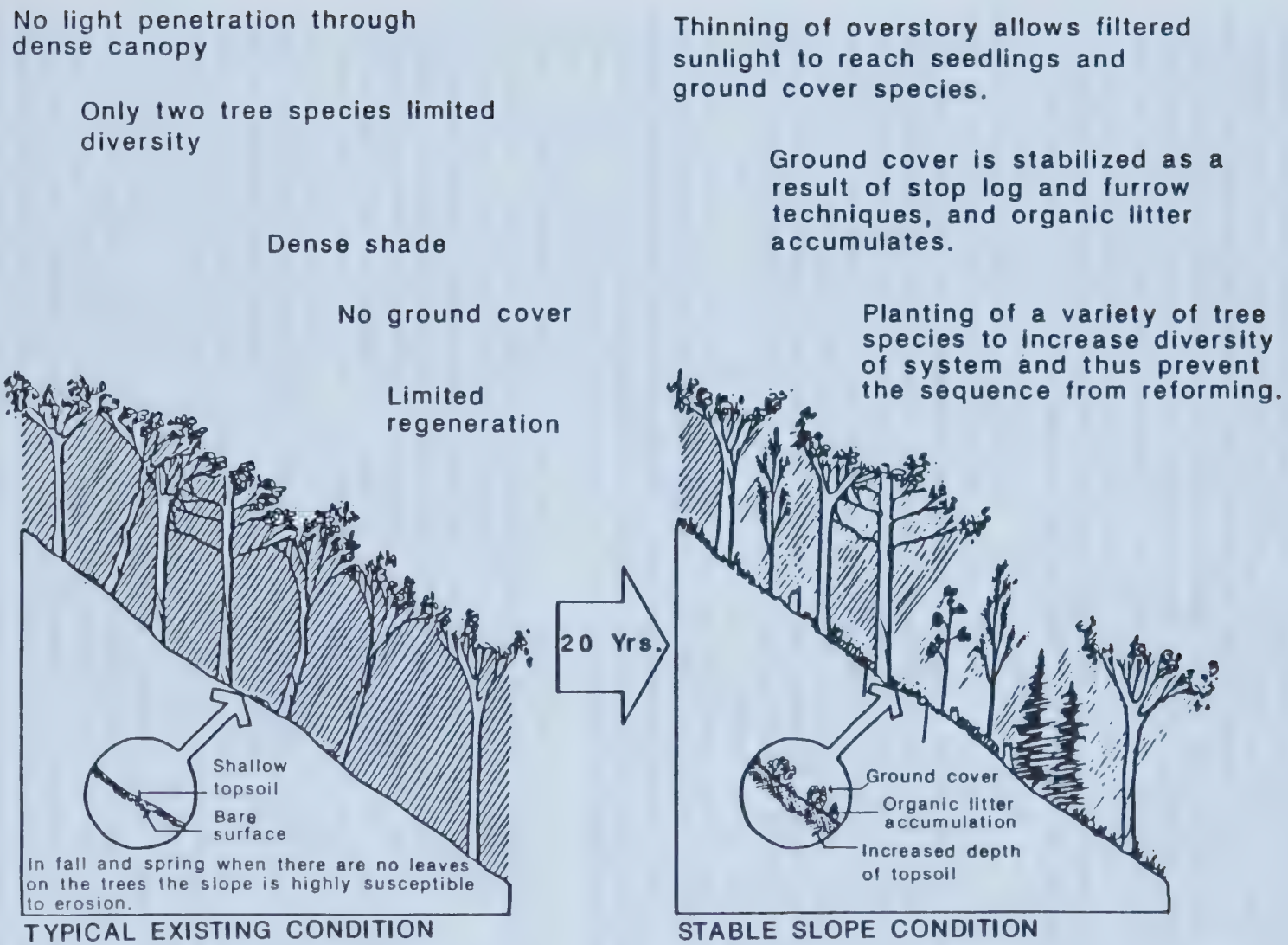

No light penetration through dense canopy
Only two tree species limited diversity
Dense shade
No ground cover
Limited regeneration
Shallow topsoil
Bare surface
In fall and spring when there are no leaves on the trees the slope is highly susceptible to erosion.
TYPICAL EXISTING CONDITION
20 Yrs.
Thinning of overstory allows filtered sunlight to reach seedlings and ground cover species.
Ground cover is stabilized as a result of stop log and furrow techniques, and organic litter accumulates.
Planting of a variety of tree species to increase diversity of system and thus prevent the sequence from reforming.
Ground cover
Organic litter accumulation
Increased depth of topsoil
STABLE SLOPE CONDITION

Figure 2 – EXISTING CONDITIONS and PROPOSED STABLE SLOPE CONDITIONS for PROBLEM SECTOR 2

Problem Sector 2 is the north facing slope located below Lover's Walk along the Ottawa River, from the Rideau Canal to past Victoria Lookout. In the past, this area was dominated by large elm trees, many of which were killed by Dutch Elm Disease. The removal of the dead trees has left the overstory very sparse and the remaining trees in poor health. Also, the amount of ground cover is inadequate to provide erosion control on the slopes. As a result, the soil was slowly creeping downslope by colluvial action and there were also several water erosion channels with active talus accumulation fans at the base of the slopes. This sector was aesthetically unpleasing.

The lack of species diversity was the underlying problem in this sector. As Dutch Elm Disease progressed, many dominate elms were removed along with short lived and diseased trees. The remaining trees were not resilient enough and were unable to respond to the change adequately, due in part to the lack of species variety within the system and to the generally poor health of the trees. Ground cover was spotty and erosive forces prevented ingrowth. Vegetation did not invade the open talus areas and the drainage channels because of the coarse, stony soils and the continual movement of surface material in these areas.

This sector was stabilized by the establishment of a variety of tree, shrub, and ground cover species. These plantings established layers of vegetation which will improve the appearance of the slopes and control surface soil movement.

Problem Sector 3 is located on the upper slopes above Lover's Walk, from Wellington Street on the Rideau Canal to the Upper Parking Lot area. Bedrock dominates this sector with outcrops in some areas as sheer cliffs and in others, as ledges with shallow soil over the bedrock. Shallow veneers of soil (15-30 cm.) on steep slopes of bedrock are common in this sector. These areas are highly susceptible to erosion, often as result of tree and shrub uprooting as well as from rill and sheet erosion.

Generally, shrub vegetation dominates this sector. Because the slopes in this sector are so steep, the shrubs are forced to grow outward to intercept available sunlight. As the shrubs grow, their crowns become top heavy and lean downslope. Eventually, they are uprooted causing soil displacement and erosion. In some places, ground cover is absent because the shrubs are so dense that light does not reach the ground. In this sector, the large shrubs were pruned to the ground surface and additional ground cover species were seeded to produce a diversity of species. Where the slopes were gentle enough and the shrub cover sparse, short shrub species were planted to encourage diversity and to lessen long term maintenance requirements.

Problem Sector 4 is located in two areas, one north of Victoria Lookout and the other to the west of Victoria Lookout below the Upper Parking Lot area. These areas were open and lacked vegetative cover. This combined with the amount of debris on the slope gave this sector a very unsightly appearance. Also, poor soil conditions existed in both parts of this sector. The soils are stony and coarse textured, which hinders the establishment of vegetation.

In this sector, all non-soil material was removed from the slope. Top soil was added to the slope so that trees, shrubs, and ground covers could be established. Live branch gratings and stop logs were used to retain the topsoil.

Problem Sector 5 is located at the west end of the slopes, around the Lower Parking Lot area. Human foot traffic in this sector is the highest anywhere on the slopes because of the proximity to the parking lots and the pathway located along the Ottawa River. Soil compaction and trampling of vegetation with subsequent channelization of run-off water has resulted from people taking short-cuts across the slopes. Problems such as those in Problem Sector 1 occur locally in this sector. The key to stabilization in this sector was to curb public access to the slopes. The erosion pathways were repaired and new stairways installed to compensate for the reduced access in this area. Barrier species such as hawthorn have been planted at the edges of the slopes to discourage further public access. The dense trees and shrubs were thinned and a variety of new species planted to encourage species diversity.

PLANT ESTABLISHMENT TECHNIQUES

The use of vegetation for stabilization of steep slopes (bioengineering) and for controlling erosion in mountainous regions is wide spread in Europe (Schiechtl, 1980). Some of the techniques were modified slightly for effective use on the Parliament Hill slopes while others are available locally. A brief description of the stabilization techniques follows, amd a more detailed discussion can be found in the Parliament Hill Slope Rehabilitation-Final Technical Report (1983).

Furrow Construction

Furrow construction was designed to provide a good combination of water retention and drainage while achieving stability on low to moderate slopes up to approximately 60-70 percent. Furrows are simply ditches approximately 30 to 60 cm. wide that are dug into the slope to the depth of about a spade, constructed horizontally across the slopes. On the downhill side, thin live fascines are placed and fastened into the ground with pegs. Fascines are bundles of live woody branches tied together with twine which are capable of producing vigorous adventitious roots. Topsoil and fertilizer is added to the furrow and live rooted trees or shrubs are planted along the furrow. A typical furrow installation is shown in Figure 3.

Hedge Brushlayers

Construction of hedge brushlayers begins at the toe of the slope and progressively moves up the slope utilizing soil material from the terrace being constructed above for the terrace below. Terraces are 0.5 to 2 meters in width and are dug out of the slope such that the platform of the terrace slopes up at least 10 degrees to the outside. Branches are placed in the terraces so that only 20-25 percent of their total length sticks out beyond the terrace edge. The branches are placed crosswise in a layer and one or two large root plants are placed among the branches. The terrace is then filled with soil from the terrace above.

Stop Logs

Stop logs are a simple, basic system designed to retain topsoil and litter on steep slopes up to angles of approximately 60 percent. Rot-resistant logs are placed horizontally across the slope and fastened to the slope by reinforcing rods driven at right angles into the slope surface. They are used where the chance of soil washing out from underneath the logs is minimum. Trees, shrubs and ground covers are planted between the stop logs. Figure 4 illustrates stop log construction.

Branch Layering of Gullies

Storm water gullies are reclaimed using branch layering. Branches of readily rooting species are laid into the gully butt end first in a fishbone pattern with their tips to the outside. The branch packs are tied to a cross beam of light timber or a live branch at 2 meter intervals. Each layer of branches and cross beams is covered with topsoil so that the lower parts of the branches are covered and can root. The branch layering of gullies allows live plant material to take root in gullies and thus secure the gully bed.

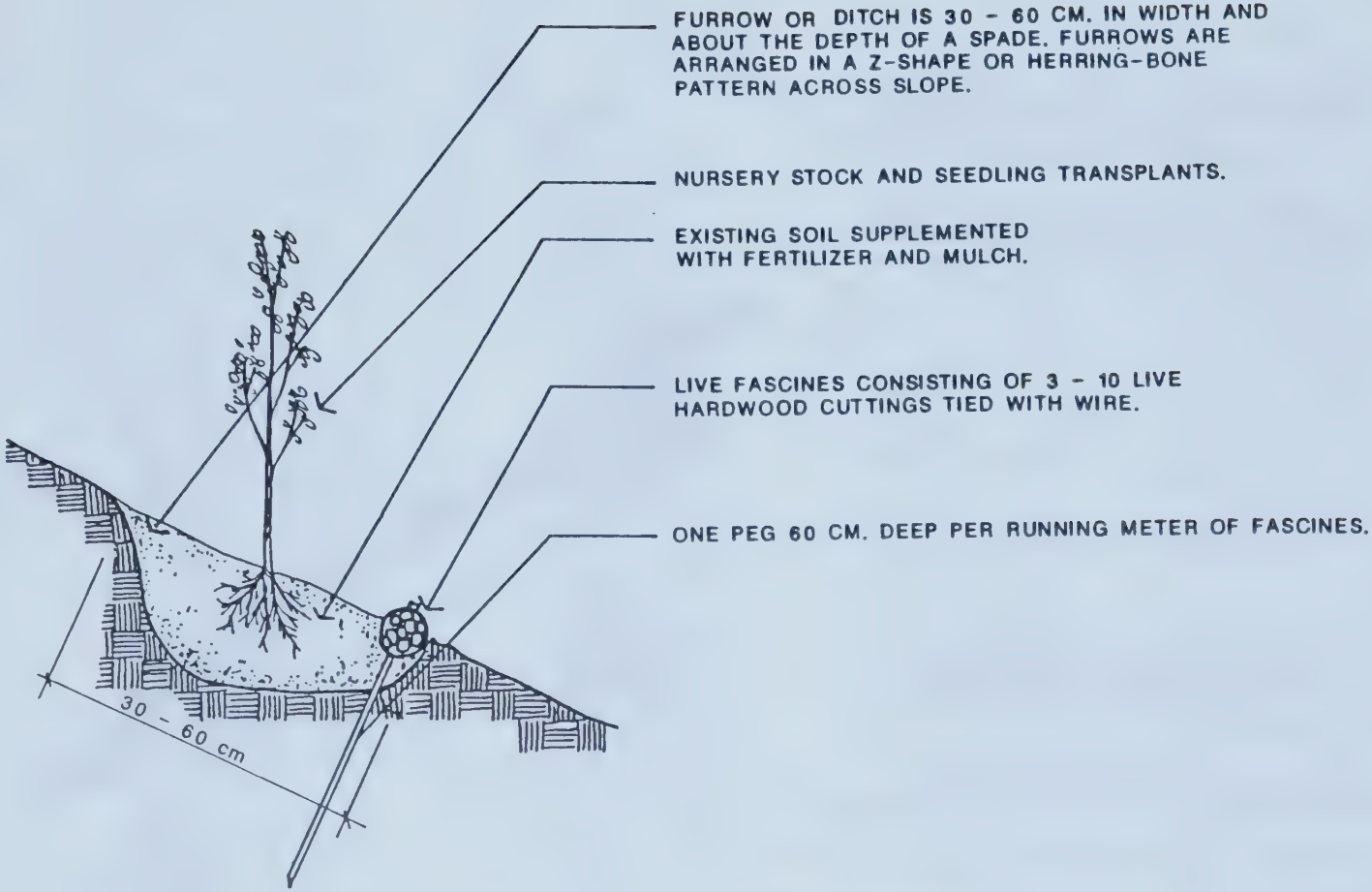

FURROW OR DITCH IS 30 - 60 CM. IN WIDTH AND ABOUT THE DEPTH OF A SPADE. FURROWS ARE ARRANGED IN A Z-SHAPE OR HERRING-BONE PATTERN ACROSS SLOPE.
NURSERY STOCK AND SEEDLING TRANSPLANTS.
EXISTING SOIL SUPPLEMENTED WITH FERTILIZER AND MULCH.
LIVE FASCINES CONSISTING OF 3 - 10 LIVE HARDWOOD CUTTINGS TIED WITH WIRE.
ONE PEG 60 CM. DEEP PER RUNNING METER OF FASCINES.
30 - 60 cm

Figure 3 - FURROW CONSTRUCTION

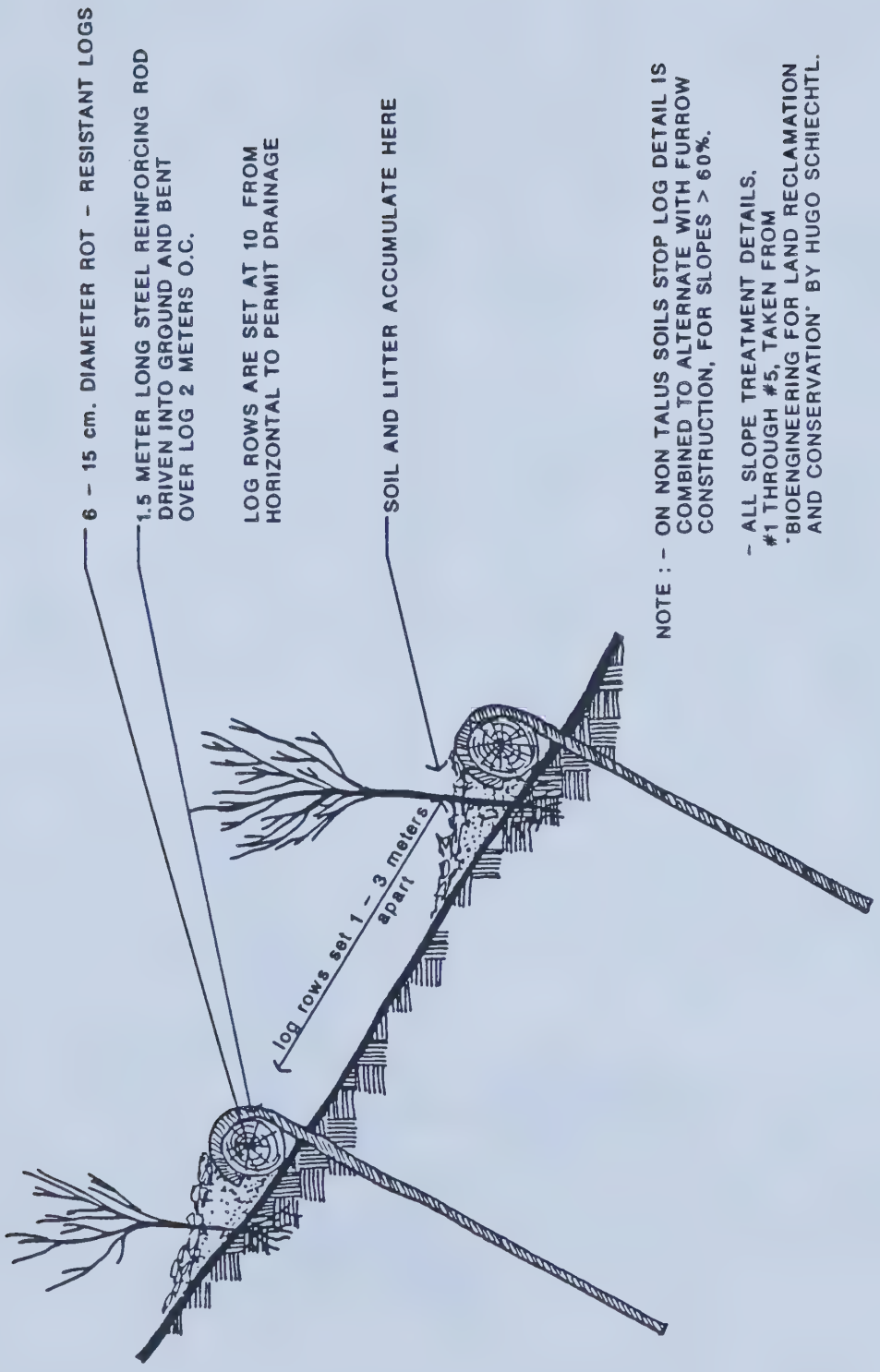

6 - 15 cm. DIAMETER ROT - RESISTANT LOGS
1.5 METER LONG STEEL REINFORCING ROD DRIVEN INTO GROUND AND BENT OVER LOG 2 METERS O.C.
LOG ROWS ARE SET AT 10 FROM HORIZONTAL TO PERMIT DRAINAGE
SOIL AND LITTER ACCUMULATE HERE
log rows set 1 - 3 meters apart
NOTE : - ON NON TALUS SOILS STOP LOG DETAIL IS COMBINED TO ALTERNATE WITH FURROW CONSTRUCTION, FOR SLOPES > 60%.
- ALL SLOPE TREATMENT DETAILS, #1 THROUGH #5, TAKEN FROM 'BIOENGINEERING FOR LAND RECLAMATION AND CONSERVATION' BY HUGO SCHIECHTL.

Figure 4 - STOP - LOG CONSTRUCTION

Live Slope Gratings

Live slope gratings are utilized on steep slopes where erosion or compaction makes it difficult to establish vegetation. The gratings support the addition of topsoil, essential to the successful rehabilitation of these types of sites. Live slope gratings (Figure 5) are constructed by leaning trees or timber poles against the slope and connecting them to each other by poles laid horizontally across the slope such that 2 meter by 2 meter squares are produced. Live hardwood poles are driven into the existing ground surface at the junctions of the squares so that the horizontal poles are supported. Topsoil is added to the squares and plant material is established.

Mulch Netting

Mulch netting is a biodegradable mesh composed of either woven plastic or heavy jute fibres. When secured to the slope surface, it provides surface stabilization in areas where there is little or no ground vegetation present and provides temporary erosion control while grasses and other plants become established. Mulch netting is installed after the ground surface has been prepared and the desired grass and wildflower seed has been scattered on the surface. Mulch netting prevents the seeds from washing off the surface so that successful germination is improved.

Hydroseeding

Hydroseeding is the application of grass and legume seed along with mulch, stabilizer, and fertilizer to the soil surface in a slurry. Hydroseeding protects the exposed surface until the grass has a chance to become established. It is used in combination with mulch netting on steeper slopes to ensure that the seed adheres to the soil surface. Also, it can be used with any of the above stabilization techniques between the rows of planted vegetation for additional erosion control.

CONSTRUCTION SPECIFICATIONS AND SCHEDULING

The Problem Sector areas were used as the basis for scheduling the construction over a five year period from 1983 to 1987. Detailed species listings, together with numbers of plantings by species and plant establishment techniques, were developed for each specific management unit within the Problem Sector. The species types and numbers and planting techniques were aggregated to determine the construction specification for each individual Problem Sector and these were used as the basis for the tendering documents and inspections of construction.

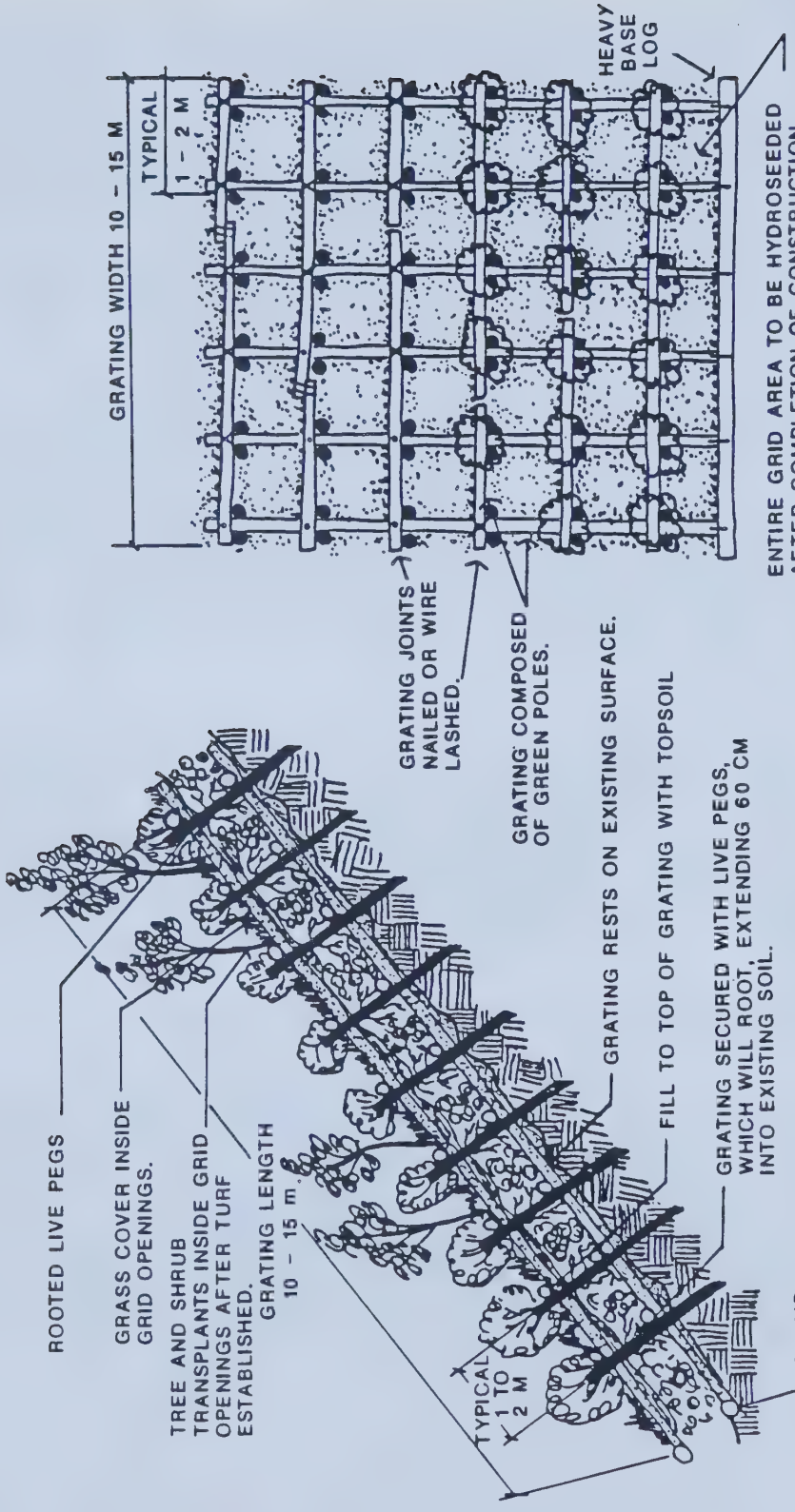

GRATING WIDTH 10 – 15 M
TYPICAL 1 – 2 M
HEAVY BASE LOG
ENTIRE GRID AREA TO BE HYDROSEEDED AFTER COMPLETION OF CONSTRUCTION.
ELEVATION
GRATING JOINTS NAILED OR WIRE LASHED.
GRATING COMPOSED OF GREEN POLES.
GRATING RESTS ON EXISTING SURFACE.
FILL TO TOP OF GRATING WITH TOPSOIL
GRATING SECURED WITH LIVE PEGS, WHICH WILL ROOT, EXTENDING 60 CM INTO EXISTING SOIL.
CLAMP
TYPICAL 1 TO 2 M
ROOTED LIVE PEGS
GRASS COVER INSIDE GRID OPENINGS.
TREE AND SHRUB TRANSPLANTS INSIDE GRID OPENINGS AFTER TURF ESTABLISHED.
GRATING LENGTH 10 – 15 m
SECTION

Figure 5 – LIVE SLOPE GRATINGS

Approximately 160,000 stems of overstory and understory plants were planted on 4.3 ha. of the site over the five year period.

SUMMARY

Prior to slope rehabilitation, surface sheet erosion, rill and gully erosion combined with the generally poor tree and shrub conditions on the Parliament Hill Slopes produced unstable and aesthetically unpleasing slopes. A master plan was prepared for the entire slope which consisted of planting a variety of native overstory and understory vegetation species in order to enhance species diversity and improve the stability of the vegetative community. Plant establishment techniques developed for stabilizing steep slopes in Europe, referred to bioengineering techniques, were used on site. Approximately 160,000 stems of overstory and understory vegetation were planted on 4.3 ha. Construction was phased over a five year period and was completed in 1987.

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SOIL EROSION AND ITS CONTROL IN ICELAND.

by

Sigurdur Greipsson

Queen's University Kingston, Ontario, Canada 30 April 1986

*Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

ABSTRACT

The Soil Conservation Service of Iceland was establish in 1907. Its main task is to control wind-erosion, the reclamation of eroded lands and supervision of all rangelands. Since its settlement, Iceland has experienced disasterous erosion, especially in the volcanic zone. Iceland has lost over one half of its vegetation cover since it was settled. Soils in the volcanic zone are mostly made up of volcanic ash and have a very small clay component. These soils therefore have very low resistance to grazing and trampling. Overgrazing has reduced the vegetation cover and in some cases has initiated erosion. Other factors have also contributed to the destruction. The SCSI use the native grass Elymus arenarius to stabilize drifting sands. The SCSI use airplanes to disperse seeds (Festuca rubra) and fertilizers. Areas protected by the SCSI now comprise 2% of Iceland, some of these areas such as costal sands require a long term protection.

THE ESTABLISHMENT OF THE ICEKABDIC SOIL CONSERVATION SERVICE.

The oldest legislation on sand reclamation in Iceland dates back to 1895. In 1907 an act on "Forestry and Prevention of the Erosion of Land" was enacted and a special Sand Reclamation representative was engaged (Runolfsson, 1978). The Soil Conservation Service of Iceland (SCSI) was established the same year. The laws were just statements of intent, because of shortage of funds and lack of knowledge to solve problems of erosion. Since Iceland was Danish territory until 1945, Danes were sent to give advice, but their reclamation work did not always fit into Icelandic situations. In 1914, new legislation separated forestry and reclamation. After 1920 the SCSI began to expand, due to increasing government funds. The greatest effort was made when SCSI headquarters were established in Gunnarsholt which is in the volcanic area of southern Iceland. In 1965 the service operation and task of the SCSI was extended and are now as follows: 1). Reclamation of eroded areas and control of wind erosion. 2). Protection of rangelands. 3). In 1975 a third item was added to the SCSI agenda: monitoring of rangelands. I will only concentrate on the first SCSI task. This paper is partly based on Mr. Sveinn Runolfsson's article; Soil conservation in Iceland, in the journal; The Breakdown and Restoration of Ecosystems, 1978.

SOIL EROSION IN ICELAND.

Icelandic sagas state that when Iceland was found (around A.D. 870) its woodlands extended from the beach to the mountains. This statement is probably true, but these woods were low birch and salix woods, and mainly in the lowlands. There were no large herbivores before the settlement, so the vegetation was in "climax" condition. It has been estimated that at the beginning of the settlement at least 60% of Iceland were vegetated, but now it is only 20% - 25%, and only 1% is now wooded (Thorsteinsson, 1973). More than half of the vegetation and the soil mantle has been lost during ca. 1100 yr. The main reason for the losses is the human use of the vegetation. Iceland become fully settled around A.D. 950 and soon after that its vegetation cover started to decline, especially woodlands, due to wood-cutting, burning and grazing of livestock. Birch woods were heavily grazed, especially in the spring and fall and that hindered the regeneration of many woodlands. Other factors have also contributed to the destruction, e.g. deterioration of the climate, volcanic eruptions and glacier burst (debacles). Iceland's climate which is cool-temperate, moist, and with frequent and changing winds (Einarsson, 1976), and the short growing season, are not very hospitable for plant growth.

Soil erosion in Iceland has mainly been on its volcanic zone which lies through the mid part of the island. Due to high volcanic activity, the soils on this volcanic zone are mainly of silt, fine sand and some coarser sand, with very little, if any, clay material (Johannesson, 1960). Soils within the volcanic zone are porous and dry, and highly suceptible to wind erosion if the vegetation cover is disturbed (Runolfsson, 1978). Because of the soils' texture it has low resistance to grazing and trampling, so with intense grazing its vetetational cover was lowered and erosion soon followed. Overgrazing on the volcanic zone has reduced soils resistance for erosion and is probably the main factor to blame for the disasterous erosion which have taken place. Pedological studies show that soil thickening in the lowlands was low and almost constant before the settlement, but after the settlement it increased rapidly due to soil erosion from the highland (Thorarinsson, 1974). The erosion was so intensive, that even wetlands in the highlands have become totally eroded. What usually happens in wind erosion is that the smallest soils particles are carried away as dust, but the larger particles roll on the ground and are a great tool for the erosion. Those larger soils particles accumulate on nearby areas and weaken the soils' resistance for erosion, due to difficulties for plant roots reaching to water. Intensive grazing also lowered soils resistance to volcanic ash. falls of ash are frequent due to high volconic activity in Iceland and that has also started soil erosion. At present, erosion is highest in the zone between 100 and 400 m above sea level. Since 1975 the ISCS has mostly concentrated on halting the erosion belove 400 m. Reclamation of the highlands (above 400 m) is more difficult because of poorer growth conditions and lack of suitable plants. Some local areas in Iceland have had and still have very low resistance to grazing, especially areas around the glaciers, which have been retreating in this century and often have left behind sands which have been tools for erosion (Bjornsson, 1979). When protected from grazing, sand-binding plants like Elymus arenarius and Salix ssp. can easily stabilize those sands. Glacier burst are frequent, due to volcanic activity under the glaciers and can cause erosion or create large

areas of sands which blows on nearby areas (Malin, 1981). Such sands are difficult to revegetate due to repeated glacier bursts. Glacical rivers have high eroding power which can initiate soil erosion (Rist, 1983). Areas north of the three largest glaciers in Iceland are in a "rain-shadow" which means that they are literally cool-deserts. Those areas are also on the volcanic zone and are a constant source for sand bowls. Vegetation cover is also very weak on high mountainous areas and in coastal areas.

LAND RECLAMATION.

All areas under SCSI control are fenced off and protected from grazing. The SCSI can take any land and protect it as long as needed in order to reclaim it, but negotiation with landowners have so far been successful. Areas fenced and treated by the SCSI over a 75-year-period are now 105, of which many have been fully reclaimed. These areas total about 2% of the country (200.000 ha), which is large considering that only 1% is cultivated, and 20% of Iceland is grazed. Some areas have been fully reclaimed and been given back to farmers. The use of aircraft in soil conservation started in 1957, and gave good results since many SCSI areas are difficult to fertilize with land-based equipment, and those areas can now been fertilized early in the summer, when most needed. SCSI have now two aircraft: a Piper Pawnee with carrying capacity of 800 kg of fertiliser and seeds and a Douglas DC3 (since 1973) which carries 4000 kg. Seeds and fertilizers are also dispersed on land in special circumstances like reclamation of gullies, erosional fronts or newly sowed areas for sand dune stabilisation. Since 1974, about 3000 tons of fertilizer have been applied annually by the SCSI mainly with the aeroplanes. Of that amount, about 60% is applied within protected areas, while the remainder is used to improve pasture lands. The SCSI have build one dam to control the fluctuating water level of a lake which gave a constant source for sand- bowls at low water, this initiating soil erosion and hindering vegetational growth on large areas. The SCSI have also built dams to divert water into dry lavas to reclaim them, with good results. Land reclamation work in Iceland has emphazised on wind-erosion, and is twofold:

a). Sand dune stabilisation.

The native grass Elymus arenarius has been used to stabilise blowing sands. At first the work was difficult due to lack of seeds, which were sampled with manpower, to problems with storing seeds and also to unsuitable varieties of seed. These problems have now been solved; sampling is now mechanized, seeds are stored in ventilated barns and the best varieties are harvested. Seeds are usually sowed with disk-plows, and best results are obtained if they are fertilized for the first three years. Erecting windbreaking timber- and stone fences was the first method to prevent sand drift and Elymus arinarius was sowed on the sheltered side. These method did not always give good results, and hay-bags are now used for sand-fences and Elymus arenarius sown as well. Elymus arenarius is also disk-plowed in continuous strips. It thrives best in blowing sands and does not form a continuous vegetative cover, but formes stable dunes. When Elymus arenarius has stabilised drifting sands, the area is usually sowed with Festuca rubra, and fertilized to revegetate the area completely. Coastal sand dunes are very common in Iceland but their vegetation is very fragile. To reclaim coastal sand dunes Elymus arenarius is sown in continuous strips just above high tide levels. Some of those coastal areas have a constant supply of sands from the sea and needs long-term protection. In the south-coast of Iceland the sand stabilization has prevented several successful fishing-village from being abandomed. Large districts were devastated by sandstorms and a number of farms were abondnomed during last century especially in

southern Iceland. The ISCS headquarters are now where sandstorms were once most prevalent.

b). Reclamation of denuded lands.

The erosion which has taken place in Iceland left vast areas denuded in the volcanic zone. To revegetate these areas, sowing Festuca rubra and dispersing fertilizers are the commonest methods. Revegetation is usually needed quickly since some denuded lands are still eroding. Because of limited resources and the size of the problem, reclaimed areas are generally only fertilized twice. The general observation has been that the sown grass (Festuca rubra) covers the areas in three or five years Several Icelandic species can extend their cover, if fertilized, especially Agrostis ssp.. Grass litter covers the ground later on and mosses become dominant. Still later, dwarf shrubs (Salix ssp.) may become dominant. However, very little is actually known about vegetational succession in the reseeded areas and or how often fertilizers need to be applied to ensure continued succession. Effects can be very local.

Over 50 grass species and many varieties mostly imported as seed from the U.S.A. and Canada have been tested for land reclamation at the ISCS headquarters at Gunnarsholt (Runolfsson, 1978). Grass species mostly needed are those which can tolerate harsh climate and low nutrient status of soils, but also produce suitable vegetational cover. Of grasses tested Festuca rubra, Poa pratensis, Bromus inermis, Phleum pratensis and Agrostis tenuis have given good results (Runolfsson, 1978). One of the most promising grass species now tested is Deschampsia ssp., a wild species from Alaska which has only been cultivated for some years. Grasses are cultivated at Gunnarsholt for seed harvesting: this seed is used in reclamation work as well as imported seeds. An ongoing project to cover native seeds with weak acid to stimulate their germination. Several Lupin species have also been tested and Lupinus nootkatensis, originally from Alaska has given good results and is now cultivated. Selecting suitable varieties allows mechanized harvesting. This lupin species can grow quite well on denuded lands and general observations indicate that it can speed up vegetational succession due to its ability to bind nitrogen. It has also given very promising results in reclaiming gullies.

The reclamation of the sands at Gunnarsholt has resulted in 1500 hectares of meadows which are now used for hay-making. The ISCS have reclaimed 300 hectares in southern Iceland which farmers use for hay making. Additionally the ISCS has assisted farmers in other parts of Iceland to reclaim, for hay production over 3000 hectares of eroded areas. To reduce grazing pressure on vulnerable areas the ISCS have reclaimed large areas on farmers' rangelands (Runolfsson, 1978).

Although soil erosion was an overwhelming problem in the beginning of this century and there was general disbelief in the efficacy of reclamation work, it now seems, for the first time that the tide is reversed, much work , however remains to be done.

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REVEGETATION OF SANDY SLOPES*

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ABSTRACT

Sandy slopes present difficult conditions for revegetation following construction because of a number of factors including; droughtiness, infertility and temperature extremes.

The MTC conducted studies to examine the revegetation of sandy roadside slopes in northern and central Ontario. The studies focused on the use of certain sedge and prairie grass species relative to an MTC mix composed of trefoil and grass species.

After a program of seed testing and test plot planting, some understanding has been gained about the potential of these plant materials for revegetation.

Based on the first year's results, the grass species tested appear to hold immediate promise for sandy slope conditions. The use of sedge species will depend upon improving germination rates in subsequent years.

INTRODUCTION

Sandy slopes can present difficult conditions for plant growth owing to droughtiness, infertility and surface temperature extremes. In many cases, revegetation attempts on these sites have resulted in patchy plant growth, requiring further maintenance or replanting.

This paper addresses such a situation faced by the Ontario Ministry of Transportation and Communications (MTC) in some areas of central and northern Ontario. The Research and Development Branch of the MTC, at the request of the Maintenance Branch, commissioned work to examine sedges as an alternative group of plants for revegetating those sandy roadside slopes. That research program was expanded to include selected grasses also expected to hold promise for those situations.

*Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

The following is a brief discussion of the approach and findings to date from those research efforts.

APPROACH

Detailed investigations were completed for six plant species; three sedges and three grasses.

Sedges:	Carex aenea	Sedge
	C. houghtoniana	Sedge
	C. lucorum	Sedge
Grasses:	Andropogon scoparius	Little Bluestem
	Panicum virgatum	Switchgrass
	Sporobolus cryptandrus	Sand Dropseed

They were selected because they possessed a number of important characteristics.

- The test species naturally inhabit droughty, infertile sites such as sand dunes and dry prairies.
- Each is native to various parts of Ontario.
- The sedges possess rhizomes capable of vigorous growth and therefore the rapid spread of populations.
- The grasses possess widespreading and deep fibrous root systems beneficial to the stabilization of surface soils of slopes.

Once the test species were selected, detailed research was conducted in five steps to confirm their practicality for sandy slope revegetation. The steps were: literature review, seed acquisition, germination testing, test plot planting and plot monitoring. Each is briefly described.

Literature review

Extensive literature review and a contact program were carried out to obtain information on seed collection, germination treatment, storage, planting techniques and planting schedules. No literature was located about the propagation of the specific sedges selected. The species apparently have not been studied. This program therefore represented pioneer research for certain species.

Seed acquisition

While the grass seed was available commercially, the seed sources for the sedges had to be identified from native populations. This was completed primarily through a search of herbaria records.

The sedge seed source locations examined ranged across Ontario, from Parry Sound to Buckhorn to Petawawa. At each collection location, a number of factors were assessed: species presence, seed ripening stage, seed amount, habitat and accessibility. Figure 1 shows Carex lucorum seed being harvested.

Figure 1: Carex lucorum seed harvesting near Petawawa, Ontario

The grass seed required was obtained from the United States, after discussions with several North American seedhouses. Viable seed, recently harvested, was desired from plants grown in a winter hardness climatic zone similar to the study area.

The Plant Health and Plant Products Directorate of Agriculture Canada was contacted regarding the weed potential of the grass seed imported from the United States. The seed was cleared and authorized for test planting by the Federal authorities.

Seed testing

Laboratory testing was conducted on the sedge seeds to determine requirements to stimulate germination. Germination rates for grasses had already been determined by the seed company. Germination tests of the collected sedge seeds were carried out by Oseco Incorporated of Brampton.

The selection of testing techniques was determined from a review of literature. Tremendous variability of treatments and results prompted a program to test the most commonly successful treatments.

These included;

- wet stratification,
- scarification,
- pre-chill, and
- heat treatment.

Wet stratification and pre-chill treatments simulate over-wintering conditions for the seeds, while the heat treatment simulates the high temperatures often found on ground level in the sand flats that some Carex species naturally populate.

Testing was completed using variations in duration and temperature for each of the four treatments mentioned above. Combinations of the four treatments were also tested.

Test plot planting

The site selected for test planting was on an approach fill of a newly constructed overpass (North Kashe Lake Road) on Highway 11, 10 km south of Gravenhurst, Ontario. The test plots were located on north and south-facing slopes west of Highway 11. The slopes were constructed of fine sandy soils.

Within four test areas (two on the north-facing and two on the south-facing slopes), numerous individual plots were established. The plots were prepared by raking and fertilizing prior to seeding. Half of them were seeded in the fall, 1985 and the other half in the spring, 1986. Planting was completed by hand-seeding. All plots were hydromulched.

The remainder of the surrounding slopes was seeded with; Bird's-foot Trefoil (Leo), Canada Bluegrass, Creeping Red Fescue (Fortress), Hard Fescue (Biljart),

Alsike Clover and Annual Ryegrass. These are some of the species sometimes recommended by the MTC for roadside revegetation of problem sandy slopes (MTC , 1986).

Plot Monitoring

Intensive monitoring of growth was conducted in the fall, 1985, and the spring and fall 1986. Observations were made of species presence, percent cover, height, vigor and presence of fruiting structures.

SUMMARY OF FINDINGS

Findings are discussed under two main areas, seed test results and test plot results. The results, especially for seed testing were quite complex and only a summary of the highlights is presented here.

Seed test results

- All sedges tested had generally poor germination success (0 to 70%).
- All sedge seeds were slow to germinate, taking on average almost two months. Figure 2 illustrates the time taken for germination to occur in a control seed lot (no germination pre-treatments).
- Germination rates varied substantially for the same species harvested from different populations.
- Germination rates varied for the same species and population harvested at different times during the growing season.
- Carex lucorum provided the highest germination rates of the three sedge species tested.
- Of all pre-treatments, only those involving scarification appeared to result in improved germination success.

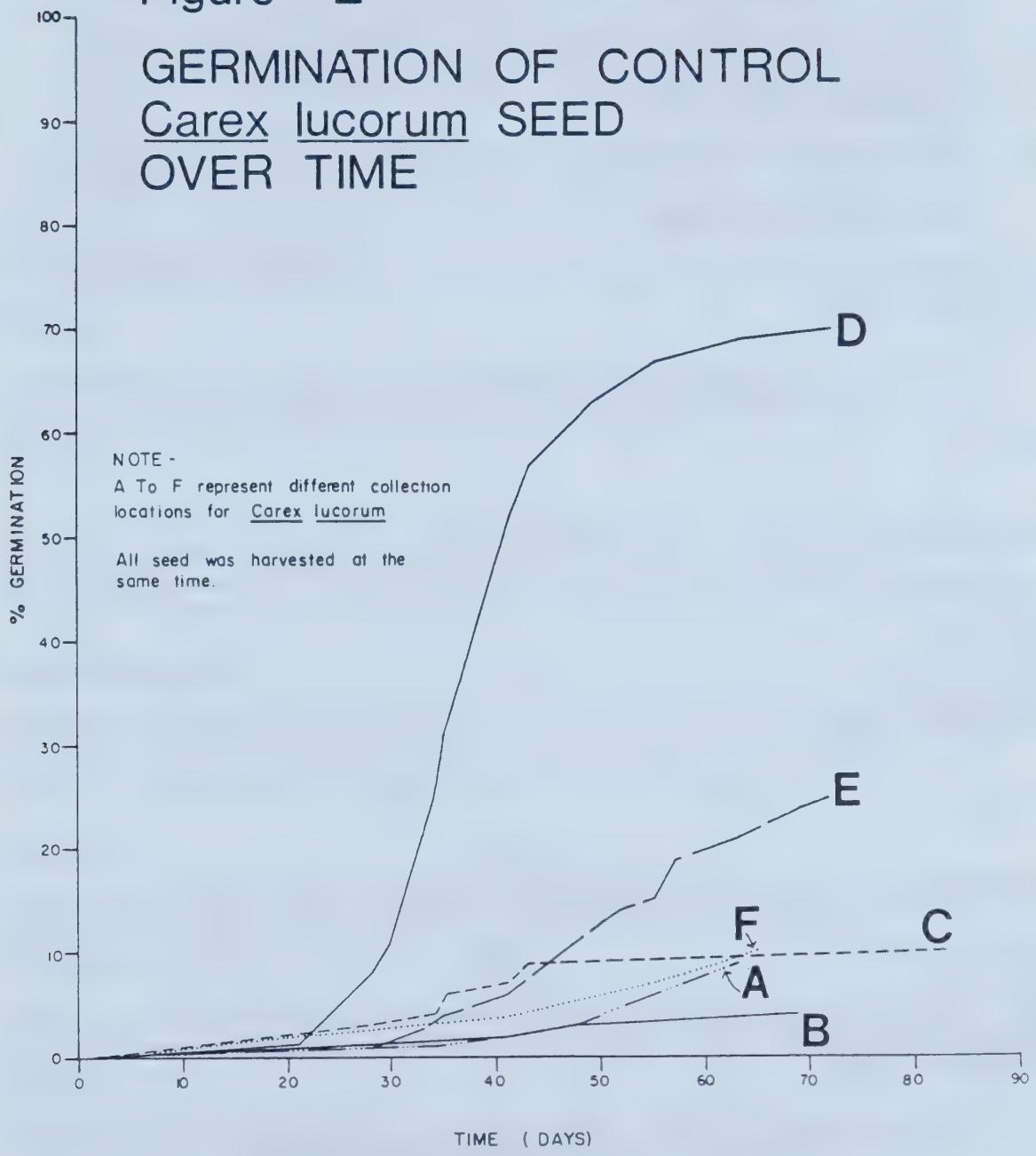
The following summarizes germination rates for each test species. Rates for grasses were determined by Sharp Brothers Seed Company, Kansas.

SUMMARY OF GERMINATION TESTS

Species	Germination Rates (%)
Little Bluestem	78
Sand Dropseed	77
Switchgrass	97
Carex lucorum	1 to 70
C. houghtoniana	0 to 5
C. aenea	1 to 36

Figure 2

GERMINATION OF CONTROL *Carex lucorum* SEED OVER TIME



Test plot results (first season)

- Spring planting had a higher degree of success than fall planting
- Both Little Bluestem and Switchgrass provided almost 50% plot cover at a rate of 60 kg/ha
- Other species tested, particularly the sedges, showed a poor growth response: Carex lucorum produced small amounts of cover: C. houghtoniana did not appear.
- The remainder of the slope, which received the MTC seed mix, displayed generally more complete coverage than any of the test plots. The MTC mix was applied at 100 kg/ha.

The following summarizes the vegetation cover for the test species for both fall and spring planting.

SUMMARY OF TEST PLOT COVER

Fall:

Test Species	Amount of Plot Cover (%)
Little Bluestem	1
Switchgrass	1
Sand Dropseed	0 to 2
Carex lucorum	0 to 1
C. houghtoniana	0

Spring:

Test Species	Amount of Plot Cover (%)
Little Bluestem	5 to 40
Switchgrass	20 to 30
Sand Dropseed	7 to 10
Carex lucorum	0 to 2
C. houghtoniana	0

IMPLICATIONS FOR REVEGETATION

This program has revealed numerous implications for the use of the test grasses and sedges for the revegetation of sandy slopes.

Sedges

The practicality of the sedges studied for revegetating sandy, erodible, roadside slopes appears limited by a number of factors.

- In Ontario, seed availability is limited to scattered known populations: collections for large-scale propagation may be expensive.
- Germination rates were generally low and very variable; commercial propagation over several years could reduce the variability. Vegetative reproduction may be a more reliable and less costly means of propagation.
- Most germination rates were slow. These three species may not present an instant vegetation cover as do some of the more traditional cover crop grasses (e.g., Rye).

These limiting factors likely do not relate solely to Carex lucorum, C. houghtoniana and C. aenea.

Grasses

The grasses studied present more immediate potential as alternate revegetation species. The seed is commercially available with high germination rates. There would be no delay in locating or developing seed sources.

These conclusions are based upon observations of growth after one field season. Further studies are planned to determine the longevity of the test species to the infertile, droughty roadside conditions.

Acknowledgements

The authors gratefully acknowledge a number of individuals for their comments on this article; Mr. R. Dell (Ministry of Transportation and Communications) and Messrs. D. Osmond and C. Hughes (Gartner Lee Limited).

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Ministry of Transportation and Communications, 1986. Turf Establishment. Landscape Operations Unit, Maintenance Branch.

THE SUDBURY REGIONAL LAND RECLAMATION PROGRAMME - AN ECOLOGIST'S PERSPECTIVE*

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ABSTRACT

Whereas the operational procedures involved in the Sudbury Regional Land Reclamation Programme are relatively simple, its ecological implications are varied and often complex. On the degraded sites themselves there is the need to fully understand the factors limiting plant growth and to predict the ultimate fate of these sites if not treated by reclamation procedures. In the case of those plants that have evolved metal-tolerance, we seek to understand not only the mechanism of tolerance, but also something of the origin of the plants themselves. There is a need to more fully understand the mechanism by which limestone application detoxifies the soil, and to determine the extent to which toxic metals cycle in the ecosystem following revegetation. Once the soil is detoxified and a grass-legume mixture is established, we must monitor colonization and observe the interactions of the colonists so that we can manage the land if necessary, in order to achieve a stable, quasi-natural ecosystem. The nutrient cycle must be understood, so that we do not limit the full development of the new biotic community for lack of nutrient capital. We need especially to ensure that all necessary microbiota are present so as to effect both the mineralization of accumulated organic matter and the biological fixation of atmospheric nitrogen. Finally we must understand and, if necessary, manage the revegetated area, treating it as a total landscape rather than as a collection of individual entities.

INTRODUCTION

The rehabilitation of land can be approached from many viewpoints, and its practitioners come from many different backgrounds. The background and training of the practitioner will have a marked effect upon the methodology used and the end product aimed at, even though these may be, to varying degrees, dictated by the industrialist, by the agency paying for the rehabilitation if other than the industrialist, by land-use planners or even by legislation. The Sudbury Regional Land Reclamation Programme, by virtue of the type of environmental damage involved, because of the large spatial extent of the damage and in view of the acceptance, until recently, of scarred land as an inevitable "fact of life", has created an unusual opportunity for diversity of approach and for experimentation. Because the objectives of the programme are primarily those of image improvement, which in the broadest sense means the establishmen of <u>some sort</u> of vegetation (so long as it is green), there has not, up to the present, been pressure applied to create an economically

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

productive landscape. It has been possible, therefore, for the ecologist to use his or her knowledge and ecological sensibilities, both in the initial treatment of land and in the monitoring and analysis of the results, as well as in the selective enhancement of the plant cover initially achieved.

ENVIRONMENTAL DEGRADATION IN SUDBURY, EARLY RECLAMATION EFFORTS AND THE SUDBURY REGIONAL LAND RECLAMATION PROGRAMME

The details of the history of environmental degradation and rehabilitation in the Sudbury area have been documented at length elsewhere (Winterhalder, 1984). In a nutshell, sulphur dioxide fumigation and copper and nickel particulate contamination since the turn of the century, in combination with logging, fire, soil erosion and enhanced frost action, have created a landscape bare, or almost bare, of vegetation, and a soil that is extremely acid, contaminated with copper and nickel, and highly toxic to all but those plants which have evolved tolerance. Experiments initiated at Laurentian University in 1971 indicated that soil properties were far more important than atmospheric quality in the restriction of plant growth in the Sudbury area, and it was found that soils could be detoxified by the application of ground limestone. At first glance, this appeared to be a simple case of a single limiting factor (i.e. low pH). As an environmental factor, however, pH rarely operates alone. While Dansereau's (1966) "Law of Factorial Control" distinguishes the limiting or "discrepant" factor from general holocoenotic effects of the environment, we have a case here of an apparent single factor possessing its own particular suite of dependant and interacting factors, a sort of "oligocoenosis". It was further shown that, where the soil was covered with a stony mantle resulting from the removal of fine particles by soil erosion (and aided, no doubt, by frost action), the surface application of ground limestone was in itself sufficient to initiate plant growth. Limestone was washed into the soil under the stony mantle, thereby neutralizing it, so that windblown seeds of native and naturalized plants could germinate. The stony mantle formed a moisture-conserving mulch. However, although the application of limestone is in itself sufficient to initiate volunteer plant establishment, the SRLRP technique also involves the application of fertilizer and of grass and legume seeds, a point that will be discussed later.

THE TRIGGER FACTOR CONCEPT

One of the most intriguing outcomes of our research on techniques for revegetating the Sudbury barrens has been the observation that a single surface application of limestone is sufficient to detoxify the soil such that the spontaneous germination and establishment of plants from the dormant seedbank and from the seed rain occurs. This phenomenon is dicussed fully by Winterhalder (1983b).

TO SEED OR NOT TO SEED

This question has arisen as a result of the trigger factor effect

mentioned above. If the application of limestone alone is sufficient to initiate plant growth, then a number of arguments could be produced favouring the elimination of fertilizing and seeding as now practiced. There would be an evident economic advantage to this approach, while from the ecological standpoint it could be argued that the introduction of exotics should be avoided wherever possible. The idea of creating a woodland with an understory of agronomic grasses may at first seem to be ecologically inappropriate. In actual fact, however, there is a tendency for woody species to become more important and herbaceous species less important during the years that follow grassing (Winterhalder, 1985). The potential benefits of the legumes in the seed-mixture to the growth of woody plants should also be remembered. In one of the more successful pine plantations on revegetated land, near Wahnapitae, there is a dense understory of Birdsfoot Trefoil (Lotus corniculatus), and both conifer and legume seem to be thriving.

Another question that must be considered is that of the difference in colonizer spacing between seeded and non-seeded areas, and the effect on later competition. If the grass-legume mixture is established as an open community, as practiced in the SRLRP, then the woody plants that colonize will be found in a somewhat random arrangement, with adequate space between the seedlings. If, however, the site is limed only, then the colonizing birches, willows and poplars tend to form a dense stand that will presumably lead to vigorous competition until certain individuals can achieve dominance. This phenomenon is shown in Table 1, where the woody plants on two 1000 metre plots, one limed, fertilized and seeded, the other merely limed, are recorded.

Table 1 . -- Percent Cover and Importance Value (Cover/Frequency Index) achieved in two years by woody colonizers on a limed, fertilized and seeded plot and on a unseeded, unfertilized limed plot

Species	Seeded Plot		Unseeded Plot	
	% cover	IV	% cover	IV
Populus tremuloides	0.6	1.5	9.1	29.1
Salix spp.	0.1	0.9	5.5	20.1
Betula papyrifera	0.0	0.0	0.4	4.5
Populus grandidentata	0.0	0.0	0	3.2

THE DETOXIFYING MECHANISM

Whereas the function of liming an acid soil is normally considered to be that of neutralization, it is possible that the phenomenon is more complex than this on the Sudbury barrens. As discussed in Winterhalder (1983b), it is possible that both the alkalinity component and the calcium component play a role in detoxification (a phenomenon called "confounded synergism" by the author). While the hydroxyl ions produced by the limestone may precipitate out any free

or adsorbed copper and nickel ions, as well as converting aluminum ions to less toxic hydroxylated ion-species, the calcium ions assist the roots themselves by improving plasma membrane integrity and competing with the toxic metal ions for exchange and uptake sites.

PHOSPHORUS AND THE CONCEPT OF NUTRIENT CAPITAL

Beadle and Burges (1949) have suggested that a limited supply of phosphorus in a soil or in a soil parent material can limit the type of plant community that will ultimately occupy that soil. Since it has been shown that phosphorus is the second limiting factor after neutralizing Sudbury barren soils (sandy soils at any rate), the possibility of phosphorus delimitation ultimately occurring should be seriously considered. There is a need for the development of a phosphorus budget for the revegetated system so that predictions can be made. One possible ameliorative measure that might be used in areas prone to phosphorus deficiency would be the application of ground rock phosphate as a slow-release source of phosphorus (and, incidentally, calcium). There is a deposit of this material in northern Ontario, but it does not appear to be economical to exploit it at this time.

It is likely that most of the phosphorus found in barren soils will be present as phytin (inositol hexaphosphate) in the humus, rather than as unweathered apatites. It might, therefore, be expected that the amount of phosphorus in the soil will be proportional to the amount of organic matter. Although such a correlation has yet to be carried out, preliminary studies (Winterhalder, 1987b) show a modest correlation between total phosphorus content and Kjeldahl nitrogen (which is primarily a measure of organic nitrogen).

THE ROLE OF NITROGEN FIXERS

While the possibility that phosphorus could limit biomass production is a realistic one, nitrogen does not present the same problem, since it is available in vast quantities in the atmosphere. The problem in this case is how to "fix" the atmospheric dinitrogen molecule such that it can be used by living organisms. Organisms capable of carrying out this "fixation" fall into two groups - those that are free-living in the soil and those that are symbiotic.

There are two main groups of free-living nitrogen-fixers - bacteria and cyanobacteria (normally known as blue-green algae). Blue-green algae prefer a near-neutral pH, and are rare in Sudbury's barren soils (C. Johnson, Trent University, personal communication), where green algae are more common. With respect to free-living bacteria, an organism resembling Azotobacter , capable of growing on nitrogen-free agar, has been isolated from Sudbury's barren soils, and nitrogenase activity has been demonstrated in this organism in agar culture. Recent attempts to demonstrate nitrogenase activity in barren soils, using the acetylene-reduction technique, have been unsuccessful, even when the soils were primed with glucose or amended with limestone (Winterhalder, 1987a). Further research will continue

on this topic.

Turning to symbiotic nitrogen-fixers, the rapid spread of Birdsfoot Trefoil suggests that it is highly suited to the terrain and is actively fixing nitrogen. A preliminary survey of soil nitrogen status, however (Winterhalder, 1987b) shows little buildup of nitrogen in the soil itself within the first few years. Woody nitrogen-fixers are also of interest, and Sweet Fern (Comptonia peregrina) has colonized sporadically and is spreading vigorously. Unfortunately the native Alders (Alnus rugosa and Alnus crispa), although producing winged seeds similar to those of White Birch, do not readily volunteer on revegetated land. Experimental planting of Alder container stock is shortly to be initiated. Black Locust (Robinia pseudo-acacia) has been highly successful wherever planted. Small-scale transplants of Soap Buffalo Berry (Shepherdia canadensis) from Manitoulin Island have been highly successful, as have those of Bearberry (Arctostaphylos uva-ursi). Although the latter species is not normally considered to be a symbiotic nitrogen fixer, it has been reported as nodulated in Alaska (Sprent, 1979). The green vigorous growth of this ground-cover-forming species causes the author to suspect some form of symbiotic nitrogen fixation, possibly rhizosphere-based. The question is under investigation.

ARE WE CREATING A POTENTIAL WEED PROBLEM?

It is normally assumed that, since the barren lands are mostly distant from agricultural and horticultural pursuits, it does not really matter what we grow so long as it is green. We must bear in mind, however, that some green plants can turn from friend into foe under certain circumstances. None of the species in the seed mixture is normally considered to be a "weed", certainly not in the sense of a "noxious weed", although Birdsfoot Trefoil is listed in some weed books (eg. Mulligan, 1984), a designation that can hardly be taken seriously. It is also true that a common seed contaminant, Scentless Mayweed (Matricaria maritima), not only thrives on the revegetated land, but has invaded the grass verges and the margins of resident's yards in the village of Wahnapitae. The plant has feathery foliage and a white daisy-like flower, and is an attractive component of the prairie-like revegetated land. It presumably is not considered to be a problem in Wahnapitae, since no complaints have been received. The fact remains that the Regional Land Reclamation Programme has progressed from the more distant and extensive barrens to smaller "neighbourhood" sites. Fortunately, the nutrient-poor soils of the reclaimed sites are unlikey to harbour vast numbers of weeds that normally require high nutrient levels - those which aggressively invade domestic gardens. The Dandelion, for instance, is found occasionally on revegetated sites, but is never an aggressive colonizer as it might be, or example, in a lawn. A problem may arise, however, in gardens with soils on the acid side. For example, the common Sorrel (Rumex acetosella) thrives on revegetated land, and might well be brought into close contact with neighbourhood gardens by revegetation activities.

Perhaps a greater risk of creating a weed problem exists in the more experimental aspects of the project, where small-scale seeding and transplanting trials occur. Even one of the tree-species now planted on a regular basis, Black Locust, is thorny, can form impenetrable thickets and is looked upon by some as a weed. In Sudbury, however, this highly acid-tolerant and hardy nitrogen fixer is only used on the most difficult sites, such as the gully-eroded clay "badlands".

Included in the earlier transplanting trials, which were commenced concurrently with the grassing programme in 1987, was the small, pink-flowered shrub, Sheep Laurel (Kalmia angustifolia). The species is clearly tolerant, has attractive flowers and is evergreen. The practice of planting this species has ceased, however, following the death by Sheep Laurel poisoning of large numbers of domestics goats in the Sudbury area. Since the species is one of the few green plants available in the early spring, it is attractive to livestock but frequently lethal. Although the poisoning did not occur on revegetated land, and although goatherding is not a contemplated land use for revegetated land at this time, it seems advisable not to create a potential problem for the future.

Experimental transplanting carried out in 1981 included a "wildflower plot", in which native or naturalized plants with colourful flowers were transplanted onto grassed land and tested for their tolerance and ability to spread. One of these was Common St. John's Wort (Hypericum perforatum), normally listed as a weed. Although the plant survives and spreads, it is not aggressive on revegetated land to the extent of excluding other species, but it is always possible that its presence will be incompatible with some future, unpredicted landuse. It photosensitizes the skin of white-coated livestock, and can cause a problem if good shade is not available (Montgomery, 1964).

A further project that should be examined critically from the point of view of its "weed" implications is the sowing of commercial "wildflower" mixtures on reclaimed land, as discussed in the next section.

THE "WILDFLOWER" CONTROVERSY

The use of "wildflower" mixtures as a substitute for a groomed lawn or a landscaped yard is in vogue amongst householders at this time, encouraged by such back-to-nature magazines as "Harrowsmith". These so-called "wildflowers", however, are usually a bizarre mixture of species from a great diversity of habitats, from prairie to alpine, and could in no way be considered as "wild" when sown onto any one site. The Chairman of Sudbury's Regional Council proposed in 1983 that such wildflower mixtures be tested on selected revegetation sites. A number of trial plots were set up, and some species have proven to be quite successful, in that they have survived (or, in the case of annuals and biennials, reseeded themselves) for several years. The question arises here, not so much of "nuisance" weeds, but of the creation of a false diversity which will puzzle ecologists and

phytogeographers for years to come, unless well documented. The main concern of ecologists and naturalists in this regard is, of course, the risk that introduced species will outcompete native species. These native species are not only valuable in that they exist, but in that they presumably possess a large pool of genetic variability that will buffer them against environmental change. The exotic "wildflowers", on the other hand, are either highly selected varieties with low genetic plasticity or are best adapted to some quite different environmental regime and are therefore only marginally tolerant at the site where they are sown. The third possibility, of course, returns to the weediness factor. The so-called "wildflowers" are in many cases aggressive, semi-weedy exotics (e.g. Yarrow, Achillea millefolium , which happens already to be a colonist of grassed sites, as well as being listed as a weed in most weed manuals). Once again, however, in view of the isolated position and hostile nature of most of the Sudbury barrens, the weed potential has not been considered as serious.

Despite the above rather negative words, even the "wildflower" trials have proven to be of interest to the ecologist. First comes the question of which species will survive and whether the environment of their original habitat bears any resemblance to the Sudbury situation. The most noteworthy case is Yellow Alyssum or Cloth-of-Gold (Alyssum saxatile), a southern European species, presumably (judging by its specific epithet) growing naturally in rocky sites. It is interesting to note that this species has very successfully colonized quite shallow soil pockets in the treated barrens.

NATIVE VERSUS EXOTIC

This general question has been dealt with from several specific viewpoints in the preceding paragraps. The broader issue also merits discussion. The author's instinctive viewpoint is that the introduction of exotics should be avoided as far as possible. A more practical point of view must, however, concede that exotics have their place in such a project. Certainly the use of a grass-cover as a first stage in the ultimate production of wooded land can be justified from several viewpoints, provided that the grass cover is not such that it out-competes the woody species. The grass cover, so long as it is not too dense, provides a mulch and a more favourable microhabitat for other, slower-growing plants. It stabilizes the soil and no doubt contributes a modicum of organic matter, improving soil structure and helping to build up a healthy rhizosphere flora that may even play a role in nitrogen fixation. The role in the overall nitrogen cycle of the leguminous component of the original cover crop is obviously important in the longer term, although legumes may not "donate" much of their fixed nitrogen to the soil and to other plants in the first year or so of their growth. A valid concern, however, is that the resulting "woodland" will have an exotic grass/legume understory, rather than an understory of the native plants normally found in woodland. While it is feasible to introduce an appropriate understory by transplanting once the trees are well established, it

is possible that the presence of exotic grasses will in some way limit their establishment. The "reconstruction" of plant communities is at this time a popular pursuit, as evidenced by the periodical "Restoration and Management Notes" published by the University of Wisconsin Arboretum. Although such "restoration" on a large scale is not a declared intent of the SRLRP, especially since it would be unrealistic to contemplate the reconstruction in a short time of the original red and white pine forest, it is desirable, in the interests of diversity (both floristic and genetic) and of the potential for ecological integrity and stability, to introduce as many of the normally expected species into the revegetated sites as possible. Naveh (1982) considers one of the three foremost future tasks of the landscape ecologist to be "to replace degraded and destroyed natural bio-ecoystems by new semi-natural, attractive, diverse and stable bio-ecosystems". This should also be the intention of the Sudbury Regional Land Reclamation Programme.

The exotic may seem to be more of a potential problem when it is a woody species with a long life span. A good example of a problem to be avoided might be the planting of extensive areas with Scots Pine (Pinus sylvestris) in the close-spaced "plantation" style. Such planting creates a low-diversity landscape, and actually impoverishes the soil rather than building it up. As far as possible, the SRLRP has been urged to make sure that woody species are planted in naturalistic groupings in harmony with the landscape, whether native or exotic, and that exotics should be used sparingly and only when necessary for tolerance reasons (e.g. Black Locust) or for a combination of aesthetic and ecological reasons (e.g. the use of European and Japanese Larch on uplands to which the native Tamarack are not suited). Again, the possibility of such exotics outcompeting natives on a widespread scale is low.

THE EVOLUTION OF METAL-TOLERANT ECOTYPES

Dansereau's (1966) 9th "Law of Ecology", the "Law of Ecesis", is a re-formulation of a conclusion of Cowles (1901) in his classic work on the Lake Michigan sand dunes. Dansereau's "Law" suggests that "The resources of an unoccupied environment will first be exploited by organisms with high tolerance and generally with low requirements". In the case of the Sudbury barrens colonizers (Deschampsia caespitosa (Cox & Hutchinson, 1980), Agrostis gigantea (Hogan & Rauser, 1979), Poa compressa (Rauser & Winterhalder, 1985) and presumably Agrostis scabra and Betula pumila var. glandulifera), the required tolerance will be mainly of soil acidity and copper, nickel and aluminum toxicity. The low requirement will be for nutrients. The actual origin of the tolerant populations in Sudbury are something of a puzzle. Neither D . caespitosa nor Betula pumila is found near Sudbury in a non-contaminated environment, while the nearest known stand of Deschampsia (on Manitoulin Island) is of a different variety, suggesting that recent colonization of the Sudbury area is unlikely. The most probable explanation would be that populations of the tolerant ecotype of Deschampsia became established well before the advent of the mining industry, on

naturally mineralized soils or outcrops. It is often suggested that one of the deficiencies on Sudbury's barren soils is moisture. In many cases this is not true, especially since there are large rock outcrops which increase the effective catchment, and seepage areas are common. This probably explains the movement of Dwarf Birch up barren hillsides from its original wetland habitat.

Both Tufted Hairgrass and Dwarf Birch not only apeear to thrive on treated soils, but they continue to spread. Although fairly acid tolerant, however, it should be rememberd that Dwarf Birch is actually a fen (not bog) species (Jeglum, private communication), while Tufted Hairgrass is normally found on circumneutral or alkaline soils.

CYCLING OF METALS IN THE ECOSYSTEM

In view of the survival and spread of metal-tolerant and metal-accumulating Tufted Hairgrass following liming, the question arose as to whether this would result in the accelerated movement into the biosphere and the nutrient cycle of toxic copper and nickel. Winterhalder *et al.* (1984) showed that, while copper, nickel and aluminum were still taken up following liming, the level of uptake was reduced, especially in the case of aluminum. Nevertheless, the increase in biomass of this tolerant species following liming would probably increase the overall amount of metals in the biosphere, and possibly increase levels of these metals entering the food chain. Once a fairly stable community is achieved on revegetated land, it would be of considerable interest to study the copper, nickel and aluminum budget of the ecosystem in comparison with that in a "natural" woodland.

THE ROLE OF RELICT SPECIES

Dansereau (1966) includes amongst his 27 "Laws of Ecology" the following "Law of Persistence": "Many species, especially dominants of a community, are capable of surviving and maintaining their spatial position after their habitat and even the climate itself have ceased to favour full vitality." We can consider the Sudbury ecosystem to contain two categories of such "relict" species. In the first category fall the plants, mostly woody, that appear to have survived in semi-barren (and to some extent barren) sites since prior to the major degradation of the environment. Woody plants falling into this category included the coppiced white birch, red maple and red oak in the Birch Transition and Oak communities of Amiro and Courtin (1981). Red oak and red maple are also found as relicts in the Barren zone, where they are joined by trembling aspen. While the first three species responded to the complex stresses by taking on a coppiced form, the aspen maintained its characteristic life form, which involves the formation of clonal patches through root suckering. Other probable relicts include the Common Blueberry (*Vaccinium angustifolium*).

A second category of relict would include those plants that existed

prior to soil amelioration but are now found in a community of plants that have been introduced or have colonized during the revegetation procedure. Some of these plants clearly fall into both categories (e.g. all of the species named above). Others, however, may have been tolerant colonists of barren land, rather than relicts. They have therefore become relicts of an earlier phase still existing within the rehabilitated system. Examples would include Dwarf Birch (Betula pumila var. glandulifera) and Tufted Hairgrass (Deschampsia caespitosa).

The interesting question is whether these relicts will make a positive contribution to the new, revegetated ecosystem, either by their presence or through their reproduction. It is clear that relict birch and poplar play a positive role in that grassed areas are clearly being colonized by these species by virtue of a seed rain that presumably originates from them. Although there is not, so far, any evidence of oak recruitment from relicts on grassed land, there is some evidence of this in untreated scrub-oak woodland south of Skead, where relict oak is dominant. In the case of maple, seeds germinate on grassed land, but rarely survive the heat of the summer. It appears that soil detoxification is not at a level at which red maple seedlings can become fully established. Even the coppiced maples themselves seem beyond salvation in most areas. Without soil amelioration they show a steady year-by-year regression, in which large stems die and are replaced by smaller stems. Following soil amelioration there is some evidence of partial recovery, but this does not appear to be universal.

THE WATERSHED APPROACH

The influence of the soil treatment employed in revegetation of the Sudbury barrens clearly extends beyond the soil itself. The results of a small watershed study now in progress are reported by Skraba & Winterhalder (1986) and elsewhere in these Proceedings (Skraba & Winterhalder, 1987).

THE LANDSCAPE ECOLOGY APPROACH

This approach considers as its basic unit the whole landscape, which according to Forman and Godron (1981) is structurally a series of patches within a relatively homogeneous matrix. The original topographic mosaic of the Sudbury barrens has had superimposed upon it a mosaic of different levels of degradation. Imposed on this is a mosaic of patches in the form of relict stands (such as Trembling Aspen groves in the valleys), of species that have evolved tolerance (e.g. Tufted Hairgrass filling some moist soil pockets), and of stream corridors with their moist enriched soil and relatively rich vegetation. The land reclamation programme has superimposed upon this yet another mosaic of grass-legume cover (corridor-like along the highways), which has itself had a new mosaic imposed upon it by differential natural colonization and by tree plantations. The SRLRP is discussed from this viewpoint in Winterhalder (1987a).

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STABILIZATION OF STRESSED LANDS IN THE SUDBURY BASIN BY INCO LIMITED*

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It is my pleasure to speak to you today on the experiences of Inco Limited in the field of reclamation.

I will begin by briefly describing the operations of the company and some of the area's history. Inco Limited is the free world's largest producer of nickel and a major producer of copper and platinum group metals. We also produce significant quantities of silver, gold and selenium. The company's mines and major processing facilities are located in Ontario and Manitoba, Canada, Indonesia, the United States and in the United Kingdom. The Onatario division operations include 9 operating mines, 3 mills and a smelter, a copper refinery and a combined nickel refinery and sulphuric acid plant in Sudbury; a mine and mill at Shebandowan which is presently on standby and a nickel and cobalt refinery at Port Colborne.

1987 marks the 101'st year of Inco mining operations in the Sudbury area. Over these many years our technology has been in a state of constant change as we strive to address environmental concerns and improve production and processes to survive in a competitive world market.

In the early 1900's the two mainstays of Sudbury were lumbering and mining. As in many resource sectors of the economy, the clear cutting of the timber and the extraction and smelting of ore left an environmentally stressed landscape in the Sudbury area.

It is documented as early as 1915 that Inco personnel had become concerned with the effects of sulphur dioxide on the vegetation being produced by local farmers. In 1916 the agricultural department of Inco was formed to address these environmental concerns.

As time progressed, new improved mining, smelting and refinery methods were developed and the large smelting complex in Sudbury became a reality. The use of large smoke stacks to disperse exhaust gases were introduces and the damaging effects of smelter smoke were decreased.

*Presented at the 12th annual meeting of the Canadian Land Reclamation Association, Sudbury, Ontario on June 7 to 11 1987

Reclamation and revegetation of stressed areas and problem soils attributed to the impact of mining, milling and smelting practices has been a wide, varied and often puzzling task.

I would like to share with you today an overview of the projects we are presently working on.

SLIDE PRESENTATION COVERING

1) Tailings - dust control - revegetation
   wildlife and tree management
   equipment and methods

2) Garson sand flux and pit reclamation

3) Coniston slag reclamation

4) Levack tailings and seepage water research reclamation

5) Stressed land reclamation

After the mining stage the ore is shipped by rail cars to the mills for processing. It is at this stage that the ore is ground to a fine grain and the first step of metals recovery takes place. Through a flotation process the minerals are separated and concentrated and shipped to the smelter for further processing. The waste rock is separated at the milling stage and accounts for 97 to 98% of the ore shipped to the mills. This becomes the waste product tailings. The Copper Cliff tailings site encompasses an area of 5 500 acres and an average of 35 000 tons of tailings are being dumped per day. As a result of the large volume of sand-like material, severe dust storms may be experienced. We spray chemical sealants for approximately 7 months of the year in an attempt to minimize the chances of creating fugitive dust. We use hydroseeding equipment and other specialized equipment with boom type sprayers. In the early 70's we experimented with aerial spraying but due to the high costs it proved unfeasible. Another method we used for temporary dust control is the application of straw and crimping it into the tailings. This method reduces the effects of wind, stabilized the surfaces and the addition of the organic materials enhances our efforts when final reclamation and seeding is allowed.

Before proceeding with our ultimate dust control cover through grassing we move to our greenhouse where initial tests are carried out to see what liming and fertilizing rates are going to provide us with the most practical and economical methods for successful reclamation.

We then move into the field situation and using our agricultural equipment apply the materials and cultivation practices necessary. At present we use 25 to 30 tons of agricultural limestone, 600 lbs. of 6-24-24 fertilizer, 100 lbs. of grass seed and 80 lbs. of fall rye as a nursery crop per acre. After initial germination we then apply approximately 80 lbs. of slow release nitrogen to ensure good vigor and continued growth. Additional applications of fertilizer are applied when necessary.

The introduction of birdsfoot trefoil is carried out at a later date using a powertill seeder We try to avoid monoculture plantings in case of insect infestation destroying the whole crop.

In 1981 a large project commenced when the final grading of dams and establishment of grass on the P containmnent area began. Due to the severe slopes encountered and the already evident surface water erosion problems, we decided to clay the outer slopes to ensure encapsulation and immediate success. When feasible, we used our standard agricultural equipment but found in many areas that hydroseeding was the only safe and practical way of seeding. The project covered a four year period and has enjoyed lasting success. The one drawback of hauling materials and covering tailings is the cost. At $6 000 per acre capital disappears very quickly.

In 1976 a five year experiment on water fowl was developed. 30 ducks were brought in from Southern Ontario. The birds were pinioned and fenced in to live in the pond of the reclaimed C.D. area. Blood samples were extracted from the birds in the spring and fall and analyzed by our process technology laboratory. After the five year period it was determined by Tom Peters that there were no significant elevated metal levels in these birds. It is at this time we began investigating the possiblility of introducting more water fowl to the area. In 1985 in cooperation with the Ministry of Natural Resources and the Copper Cliff Rod and Gun Club the first group of 50 giant Canada Geese Goslings was introduced to the tailings site. They were taken from the Toronto Island area where their numbers have grown to the point they are somewhat of a nuisance. The Gun Club and Ministry rounded them up before the flight feather stage and the Ministry flew them to Sudbury. They were then transported and released in the C-D area of the tailings. The same program was carried out in 1986 and will be carried out again in the third week of June this year. Giant Canadas were not common in the Sudbury area but numerous sitings in all parts of the city are now common places.

In 1978 a joint project with Laurentian University commences to study the feasibility of growing vegetables in an underground mine to explore practicability and energy efficiency using the natural geo-thermal heat generated underground. The program experienced many successes with the different vegetable crops tested.

We have now turned our energies to growing trees underground and the second crop of 35 000 were brought up in early may for planting on our tailings and other reclaimed areas.

In 1983 the department took on a project which in general goes against our principles. This was the clear cutting of 200 acres of trees to make way for the new R area for pyrotite disposal. The project was completed in the fall of 1985 and is presently an active disposal area.

Other areas of concern in our operations are the sand pit and flux pit, providing sand for mine backfill and flux sand for our smelter operation. We report to the Ministries Pits and Quarries Personnel. We have carried out an annual program in these areas and are responsible for final grading and revegetation to ensure safety for the public and avoid fugitive dust complaints. Trees are introduces at these sites when appropriate.

In the late 60's a liming program began at the company's old Coniston smelter site to alleviate pH fluctuations in spring runoff water from the now abandoned slag piles. This program has been carried out with the spreading of 100 tons of agricultural lime both spring and fall. In 1985 I observed a natural growth of small trembling aspen and attributed it to our liming program. In 1985 a test plot of 10 acres was seeded on the slag. The successful growth validated the concept and we continue to seed 15 to 25 acres per year. We hope the vegetation will help with the water runoff and allow tree establishment in the future and enhance the aesthetics of the area.

In 1984 the reclamation of the Levack mine tailings site began with our department doing initial greenhouse and in-field tests. We were also approached by the mines' personnel to come up with a close out and decommissioning plan for the site. As a result of this we became involved in a water quality assessment. The concept of close out, leaving a natural secure landscape and water runoff quality acceptable to the Ministry of the Environment's standards, without long-term treatment, has lead us in a new direction. The concept of biological polishing ponds was introduced by Margret Kalin of Goojum Research. In cooperation with the National Research Council we have jointly investigated this possiblitiy. The results to date have showed great promise and we are still pursuing this very practical method of dealing with a long-term problem of all mining companies.

The overall close out proposal is still under design but through our initial research is becoming a near future reality.

In 1981 we began our own Stressed Land Reclamation Program on company property to complement the work being carried out by the joint efforts of municipal, regional, provincial and federal governments. We

employed 25 students for the summer and manually spread lime and fertilizer on surrounding rocky-till outcrops. The program was very successful.

We have since moved on to a mechanized operation using 4 wheel all-terrain vehicles with electric spreaders mounted on the rear of the machines. We spread pelletized lime, fertilizer and seed. The equipment has allowed us to progress with the program at an accelerated rate.

In conclusion I would like to say we at Inco are dedicated to complying with all environmental legislation and continue to take all practical measure in minimizing any adverse effects that our operations might have on the environment. We are developing new technology to reach these goals and improve the environment we all share.

THE HARDENING-OFF AND PERFORMANCE OF MINE-GROWN CONIFEROUS SEEDLINGS IN THE RECLAMATION OF ANTHROPOGENICALLY DISTURBED AND STRESSED LANDS*

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ABSTRACT

Containerized *Pinus banksiana* and *Pinus resinosa* seedlings were grown in a mine drift at the 1400 m (4600') level at INCO Ltd's Creighton Mine to age 14 weeks prior to hardening-off and out-planting on disturbed and stressed lands. Planting sites were: a) land denuded because of base-metal smelting activity, and b) an aggregate borrow pit. Both sites had been reclaimed recently by application of lime and fertilizer, and seeding to grasses and legumes.

Two crops were examined; a fall out-planted crop and a spring out-planted crop. Five hardening-off treatments were used: I) constant 13° C, II) fluctuating 13° C night, 23° C day, III) constant 8° C, IV) fluctuating 8° C night, 23° C day, and V) constant 23° C. Daytime photoperiod was 12 h for fall out-planted seedlings and 20 h for spring out-planted seedlings. Plants were assessed for degree of survival, amount of flushing and overall growth.

Best survival (spring, 90%; fall, 70%) was obtained on the site denuded by smelter activity, irrespective of season. The most effective hardening-off treatment in spring was a continuous 23° C regime whereas the most effective fall treatment was a 8° C night:23° C day regime. This same regime provided the best growth response for fall-planted seedlings of both species. Overall, seedlings at the Coniston site showed the best performance. This success is attributed to a better microenvironment.

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987

INTRODUCTION

The Sudbury area has been disturbed seriously over the past 100 years. Environmental stresses associated with logging, forest fires, base-metal extraction, smelting, and aggregate excavation have given rise to a landscape whose plant communities differ greatly from those that existed prior to human impact. Barrens, semi-barrens and coppice woodlands dominated by white birch (*Betula papyrifera* Marsh.), red maple (*Acer rubrum* L.) and poplars (*Populus* spp.) occupy many thousands of hectares in the vicinity of active smelter complexes at Copper Cliff and Falconbridge, and the former Coniston smelter site (Amiro and Courtin 1981). Reclamation efforts in some of these areas, using lime, fertilizer and herbaceous seed mixtures, have resulted in stabilization of soil conditions and the establishment of a herbaceous vegetation. Hardwoods, such as the pioneer species white birch and trembling aspen (*Populus tremuloides* Michx.), have been reestablishing naturally but conifers must be reintroduced owing to a lack of seed source. The establishment of conifers on ameliorated barrens is desirable owing to the ability of conifers to thrive on poor soils that are low both in organic matter and nutrients (Miller *et al* 1978).

In northern climates the use of greenhouse space for the production of containerized tree seedlings is expensive owing to the high costs of heating such structures. Containerized seedlings, however, have a higher rate of survival (80-90%) than bare root seedlings (40-60%) and are more desirable therefore for out-planting in disturbed areas (Sheppard 1981). The use of geothermal heat in mined-out drifts is an attractive, economic alternative and this method is being used presently at INCO Ltd's Creighton Mine for the production of forestry seedlings. In Sudbury area mines, geothermal heat increases 1 C^{o} for every 100 m of depth (Serbanescu *et al* 1982). It is possible, therefore, to select a level that provides an appropriate temperature for production of forestry seedlings with little expense except for lighting. Containerized forestry seedlings have been grown successfully underground at the Bunker Hill Mine, Kellogg, Idaho since the mid-1970's (Sheppard 1981).

Jack pine (*Pinus banksiana* Lamb.) and red pine (*Pinus resinosa* Ait.) are two commonly grown containerized pine species in eastern Canada. Previously, these two pine species have been successfully out-planted, as bare root stock, on ameliorated, disturbed and stressed

lands in the Sudbury area (Lautenbach 1985). Conifer establishment on such sites is advantageous not only for seed source renewal, but also for creating mixedwood stands to avoid monoculture and its associated ecological problems.

Basic procedures for the production of containerized tree seedlings were established in the mid-1970's (Tinus and McDonald 1979). Two crops of containerized pine seedlings are grown in greenhouses in the Northeastern Region of the Ontario Ministry of Natural Resources: a spring crop, that is out-planted in late May or early June and a summer crop that is overwintered and out-planted in the following spring. fall out-plantings of the summer-grown crop, however, both with bare root and containerized stock, have been relatively unsuccessful.

The application of a hardening-off treatment to seedlings, that have been produced from seed under stable, controlled conditions, is a process that renders the seedling less susceptible to drought and frost following out-planting in the field where it is subjected to variable but normal climatic conditions. An attempt to find a suitable hardening-off treatment for jack pine and red pine seedlings produced underground for out-planting during revegetation efforts was a major goal of the present research. Three specific points were addressed: 1) to determine the most effective temperature and photoperiod regime required for hardening-off of both spring and fall crops; 2) to observe any site-specific differences; and 3) to compare the response of the two coniferous species with respect to survival and growth. These comparisons aim to provide physiological and ecological information regarding the two tree species and to indicate how the two species might be utilized optimally for land reclamation purposes.

DESCRIPTION OF THE STUDY AREAS

The Regional Municipality of Sudbury is located in Northeastern Ontario on the southern edge of the Precambrian Shield in the transition zone between the eastern deciduous forests of the south and boreal forests of the north (Braun 1950) (Fig. 1). The topography consists of rock outcrops, steep slopes and low wet areas that are a result of the Wisconsin glaciation in the late Pleistocene.

Two areas within the Municipality were chosen as out-planting sites. An ameliorated, industrial barren site, the "Coniston" site, is located 14 km east of Sudbury (Fig. 1) and is typical of sites that have been denuded owing mainly to logging, fires and smelter fumes. The

fumes have not only impaired vegetation but also have contributed to acidification and toxic metal contamination of the soil. Recent reclamation efforts on some of these barren areas have resulted in the establishment of grasses and legumes (Winterhalder *et al* 1984). This site was ameliorated initially with lime and fertilizer in 1981 and sown with a mixture of grasses and legumes (Lautenbach 1985). Bare root jack pine and red pine seedlings were planted in 1983. At the time of the present study, trembling aspen, white birch, and willows had become established through self-seeding. The pH of the site was 4.4.

The second site is a reclaimed aggregate borrow pit, the "Whitefish" site, located 22 km southwest of Sudbury (Fig. 1). This site was reclaimed by the Ontario Ministry of Transportation and Communications in 1978 using a technique and seed mixture similar to that used at Coniston. At this site the pH was 5.4, a value that is typical of natural soils acidities found in the Boreal Forest.

METHODS AND MATERIALS

Jack pine and red pine seedlings were grown in a mined-out drift at the 1400 m (4600') level of INCO Ltd's Creighton Mine. The temperature of the level was a constant 23° C. Two sets of seedlings, 1600 jack pine and 1600 red pine were grown on benches set up on each side of the drift. The seedlings were double-seeded into Grace "Terralite" in 16 Leach "Cone-tainer" racks where each rack contained 200 63 cm^3 white polyethylene cells. The terralite in each cell was covered with 91 grade silica sand following seeding to prevent algal growth and to reflect light. Seedlings were fertilized by hand twice weekly following germination. Thinning, to one plant per cell, was done once primary needles had been developed and the seedlings were grown for approximately 14 weeks at which time hardening-off treatments were initiated. Crops were seeded in early February for spring out-planting and in mid-June for fall out-planting.

An automatic misting irrigation system was controlled by timers and the misting interval changed as the requirements of the crop changed with progressive growth. Lighting was provided by three G.C.E. 1000 W metal halide lamps (HS-MH1000-12) centred in the drift. The lamps were 2.5 m apart and *ca* 1 m above the seedlings. Photoperiod was 20 h day:4 h night. The photosynthetically active radiation flux density ranged between 150-170 $\mu E\ m^{-2}\ s^{-1}$.

Hardening-off treatments varied for each crop but were essentially variations in temperature (either 10 or 15 C^{o} below that of the initial growing temperature) and in photoperiod (12h day:12 h night for fall out-planting and 20 h day:4 h night for spring out-planting) (Table 1). Constant regimes were provided by mine environments whereas fluctuating regimes were provided in environmental growth chambers. Spring hardening-off treatments were initiated on June 4 1985 and fall hardening-off treatments were initiated on September 21 1984. All treatments were of 14 days duration. Immediately following treatment the Seedlings were out-planted into 4 25 m X 25 m plots at each site. Both sites were on a slope. Two plots were laid out on the flatter, upper portion of the site and were planted with jack pine. The two other plots were laid out on the steeper lower slope and planted with red pine. Randomization of the five treatments was by means of a 5 X 5 Latin Square Design that reduced gradient effects by confining each treatment to a single occurrence in any specific column or block (Sokal and Rolf 1981) (Fig 2). Each subplot in the Latin Square was 5m X 5 m and contained 12 seedlings. Planting was in 3 rows, 1.25 m apart, with four seedlings per row. Each seedling was spaced 1 m from its neighbour. The second out-planting was performed using the same plots but each seedling was planted in between the previously planted seedlings. The resultant spacing of 0.5 m was felt to be sufficient to prevent the possibility of competition for the duration of the experiment.

After planting, and at the end of each growing season, data were collected as follows: number of seedlings that survived, number of seedlings that flushed, initial growth height and shoot diameter (including needles), flush growth, height and diameter (including needles), and qualitative observations on degree of overall seedling and needle health. Data were analysed using Multiple Analysis of Variance (MANOVA) because of the complicated Latin Square design. Paired t-tests on mean flush length for each plot were used to determine any significance between sites. A Duncan's multiple range test, which is a midrange multiple test often used in biology, was used to compare the treatments and to find the differences when a signifance in the MANOVA was evident.

RESULTS

Fall Planting - 1984

The percentage of jack pine seedlings, out-planted in the fall, that survived to the end of the first growing season (Fig. 3), was 69% at Coniston and 76% at Whitefish. Red

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pine survival was 72% at Coniston and 37% at Whitefish. Survival of the fall planting was considered to be satisfactory except for the red pine at Whitefish.

Results from the MANOVA for degree of survival (Table 2) indicates that treatment effects were significant at both sites for both species. At both sites Duncan's multiple range test (Table 2) shows identical treatment effects. Treatment V seedlings (constant 23° C) have a lower survival rate than the constant temperature treatment I (constant 13° C) and III (constant 8° C) seedlings and the fluctuating temperature treatment II (fluctuating 13-23° C) and IV (fluctuating 8-23 ° C) have the best survival rate of all the treatments. The Duncan multiple range test for red pine at both Coniston and Whitefish showed similar trends (Table 2). Treatment V seedlings (constant 23° C) had significantly lower survival rates than the seedlings from the other treatments where the survival rate was approximately the same.

The percentage of all jack pine and red pine seedlings that flushed in spring 1985, expressed in terms of those that survived, was greater at Whitefish than at Coniston (Fig. 4). Significantly fewer red pine seedlings flushed than jack pine seedlings at both sites. A MANOVA showed no signifance of treatment with the exception of red pine at Coniston (Table 3). A Duncan's multiple range test for the Coniston red pine shows that the fluctuating temperature treatment IV (8-23° C) flushed significantly more than any of the other treatments and that the two constant temperature treatments I and III (13° and 8° C, respectively) had the lowest degree of flush.

Mean flush length for jack pine was 3.1 cm at Coniston and 3.4 cm at Whitefish (Table 4). Red pine averaged 0.6 cm at both sites (Table 4). Paired t-tests showed no significant differences between sites (p=0.05). Once again, a Duncan's multiple range test indicated that treatment IV (fluctuating 8-23° C) produced the greatest length just as it had the greatest percent of flush.

Spring planting - 1985

Three months following out-planting, percent jack pine seedling survival was 80% at Coniston and 33% at Whitefish whereas red pine survival was 82% at Coniston and 35% at Whitefish (Fig. 3). From the results of the MANOVA for degree of survival, there was no significant treatment effect for red pine at either site whereas significant

treatment effects were apparent for jack pine at both sites (Table 5). Gradient effects, owing to environmental factors, were significant for the jack pine plots at both sites and for the red pine plots at Coniston. The column effects indicate a possible environmental change downslope.

A Duncan's multiple range test of the Coniston jack pine shows that treatment I seedlings (constant 13° C) have the greatest significant survival rate, treatment III and IV seedlings (constant 8° and fluctuating 8°-23° C, respectively) have the lowest significant survival rates and treatment II and V seedlings (fluctuating 13-23° C and constant 23° C, respectively) have approximately the same moderate survival rate. For the Whitefish jack pine, treatment II seedlings (fluctuating 13-23° C) have the greatest rate of survival, and treatment III, IV and V seedlings (constant 8° C, fluctuating 8-23° C and constant 23° C, respectively) have the lowest rates of survival.

The number of jack pine seedlings that flushed, expressed as a percentage of those that survived to the end of the growing season following spring out-planting (Fig. 4), was 67% at Coniston and 68% at Whitefish. Red pine flush was extremely low; 4% at Coniston and 15% at Whitefish. The higher value at Whitefish may be a distortion because of the large summer mortality at that site. The low percentage flush in the case of red pine was expected as flushing during the first season after spring out-planting is normally not significant in this species. It should be noted also that a MANOVA performed on the jack pine data showed column effects attributed to an environmental gradient but no treatment effects.

Flush length for jack pine at Coniston was 1.2 cm whereas at Whitefish the mean was 1.1 cm (Table 4). A paired t-test indicated no significant difference ($p=0.05$) between the sites. Again, a MANOVA gave no indication of effects owing to treatment.

DISCUSSION

Hardening-off had an effect upon many aspects of seedling survival and growth of both crops. Seedling survival and establishment is related to the amount of temperature and drought stress that a seedling can endure following out-planting. Hardening-off increases seedling resistance to low temperatures (Alden and Hermann 1971) and water stress (Blake *et al* 1979) by changing either seedling morphology or physiology or both. The induction of cold

hardiness by the application of water stress, however, is still highly contraversial (Van den Dreissche 1969; Timmins and Tanaka 1976). Reduction in photoperiod also plays an important role because the onset of naturally shortened days induces cessation of growth and constitutes the initial stage of the hardening-off process (Christensson 1978). Most temperate plant species begin to develop cold resistance as the temperature is lowered gradually below 10° C (Alden and Hermann 1971), and Van den Dreissche (1969) found that Douglas-fir seedlings subjected to a low night temperature (7.5° C) and a high day temperature (24° C) were more cold hardy than seedlings that were sujected to either continuous low or continuous high temperatures.

Survival of the fall out-planted crop, for both jack pine and red pine, was lowest for seedlings hardened-off at a high (23° C) constant temperature regime with best survival occurring with fluctuating temperature treatments in concurrance with the findings of Van den Dreissche (1969).

The 12 h day photoperiod to which the fall crop was subjected may not have been short enough to induce the maximum benefit to be derived from a shortened day. Tanaka (1974) observed that in Douglas-fir an 8 h day, together with low temperatures, was essential for successful fall out-planting.

Both the highest percent flush and the greatest amount of growth was induced by the temperature treatment with greatest fluctuation (8-23° C), whereas the least amount of growth resulted from the constant low temperature (8° C) treatment. It is clear, therefore, that whereas the presence of low temperatures, either constant or fluctuating, induces a high rate of winter survival, a fluctuating regime must be imposed to induce vigorous growth the following summer.

Survival of the spring out-planted jack pine seedlings was greatest for seedlings hardened-off by more moderate treatments, constant 13° C and fluctuating 13-23° C. Red pine, however, was insensitive to any of the treatments. Growth of spring out-planted jack pine was unaffected by the hardening-off treatments and it is felt that the most important factor in the case of spring out-planting is the prevailing weather conditions. Drought tolerance could not be inferred from the data but a comparison of out-planting in spring 1984 (Naumenko 1986) with that of spring 1985 indicates that when abundant soil moisture is present during out-planting followed by a regular pattern of summer rainfall (e.g. summer 1984),

survival is considerably improved.

The present work leads to the conclusion that fall out-planting can be successful if the crop is given proper hardening-off conditions. Although mortality is slightly higher for a fall crop because of factors such as frost heaving, the loss in numbers is offset by the increase in biomass owing to flush and growth the following summer. This is especially true in the case of jack pine. There is an advantage, however, also for red pine. This species does not flush in the first summer following spring out-planting, but with fall out-planting a 38% flush at Coniston and 60% flush at Whitefish was realized and it is possible that this additional growth may result in better establishment in the long term when compared to spring out-planting.

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Table 1. Schedule of hardening-off treatments for jack pine and red pine prior to out-planting.

Treatment	Light and Temperature Regime	
	Fall 1984	Spring 1985
I	Constant 13° C	Constant 13° C
II	13° C night:23° C day	13° C night:23° C day
III	Constant 8° C	Constant 8° C
IV	8° C night:23° C day	8° C night:23° C day
V	Constant 23° C	Constant 23° C
Photoperiod	20 h day:4 h night	12 h day:12 h night

Table 2. Comparison between treatments for degree of survival, from MANOVA, for Jack Pine and Red Pine seedlings at the end of the 1985 growing season following fall 1984 outplanting.

SPECIES	CONISTON	WHITEFISH
Jack Pine	TRT[b]	TRT[d], COLUMN[a]
Red Pine	TRT[c]	TRT[e], BLOCK[a]

p = 0.05

[a] COLUMN, BLOCK significance indicates gradient effects.

[b] Coniston Jack Pine V I III II IV

[c] Coniston Red Pine V IV I III II

[d] Whitefish Jack Pine V I III II IV

[e] Whitefish Red Pine V IV II III I

(any treatments not underscored by the same line are significantly different at p = 0.05)

Table 3. Comparison between treatments for degree of flush, from MANOVA, for jack pine and red pine seedlings at theend of the 1985 growing season following fall 1984 out-planting.

SPECIES	CONISTON	WHITEFISH
Jack Pine	NS	NS
Red Pine	TRT[a]	NS

p = 0.05

[a] Coniston Red Pine I III II V IV

(any treatments not underscored by the same line are significantly different at p = 0.05)

Table 4. Comparison of flush length (cm) at the end of the 1985 growing season for jack pine and red pine out-planted in fall 1984 and spring 1985 at the Coniston and Whitefish sites.

SITE	SPECIES	FALL 1984	SPRING 1985
Coniston	Jack Pine	3.1	1.2
	Red Pine	0.6	-
Whitefish	Jack Pine	3.4	1.1
	Red Pine	0.6	-

Table 5. Comparison between treatments for degree of survival, from MANOVA, for jack pine and red pine seedlings three months following spring 1985 out-planting.

SPECIES	CONISTON	WHITEFISH
Jack Pine	TRT[b], COLUMN[a]	TRT[c], COLUMN[a]
Red Pine	COLUMN[a]	NS

p = 0.05

[a] COLUMN, BLOCK significance indicates gradient effects.

[b] Coniston jack pine

III	IV	II	V	I

[c] Whitefish red pine

III	IV	V	I	II

(any treatments not underscored by the same line are significantly different at p = 0.05)

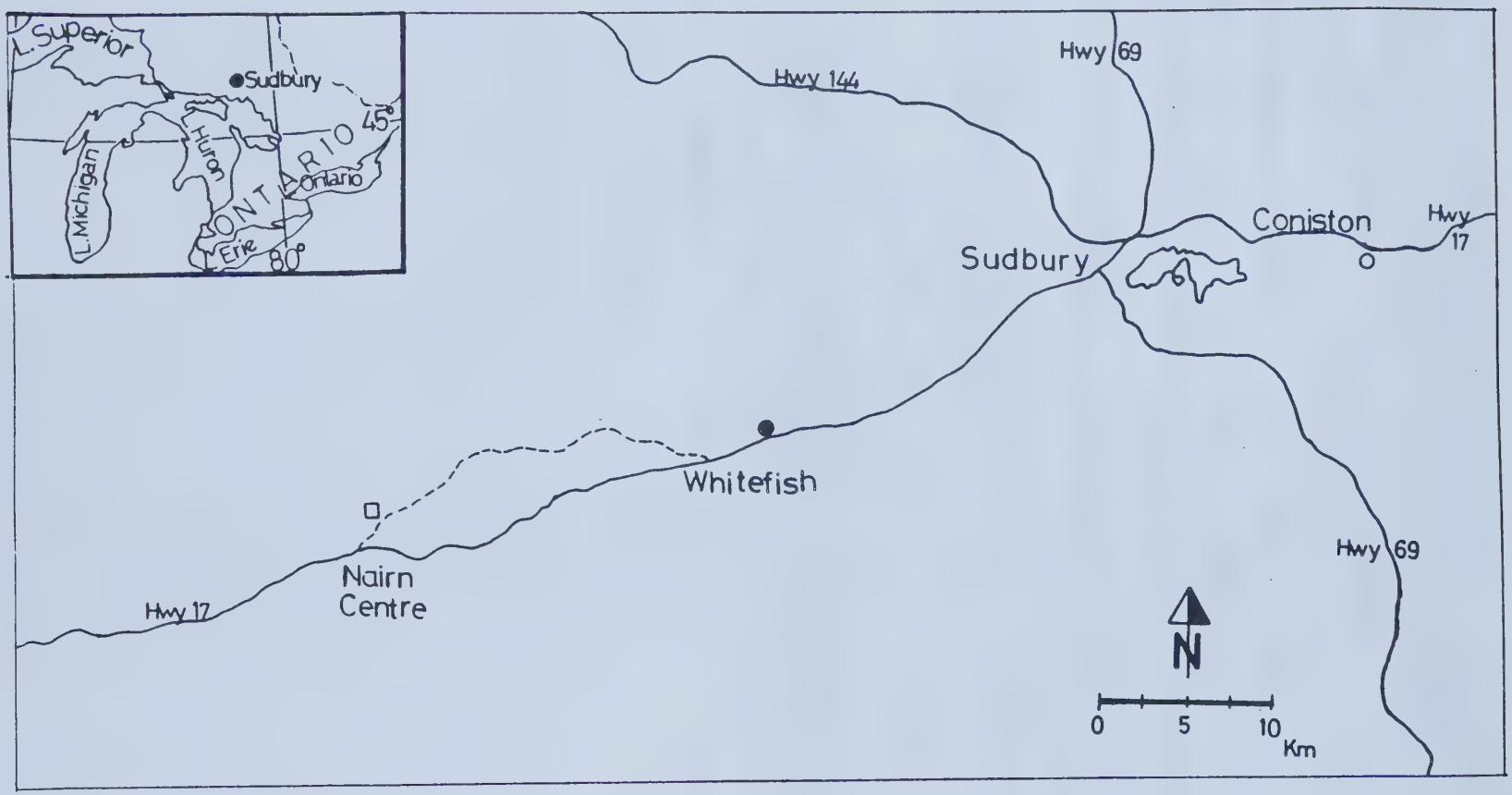

Fig. 1. Map of the Sudbury Region showing the location of of the Coniston and Whitefish sites used for out-planting of jack pine and red pine.

BLOCKS	COLUMNS				
	V	IV	I	III	II
	II	V	IV	I	III
	III	II	V	IV	I
	I	III	II	V	IV
	IV	I	III	II	V

Fig. 2. 5 X 5 Latin Square Design. Each plot was 25 x 25 m such that each treatment cell was 5 X 5 m. Roman numerals indicate the treatment number.

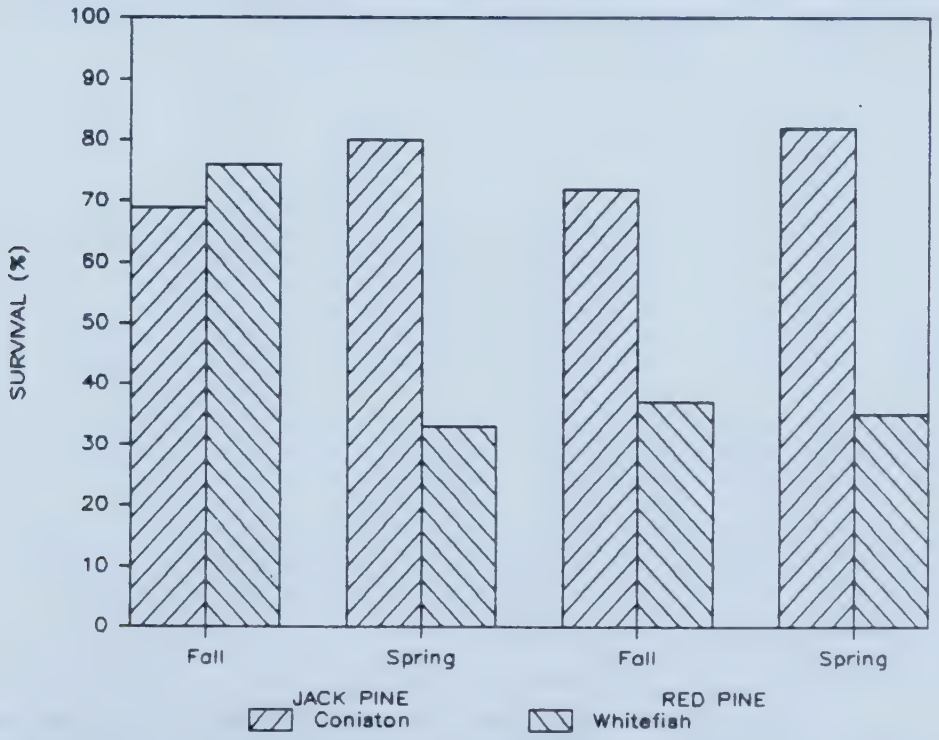

Fig. 3. Percent survival, at the end of the 1985 growing season following fall and sping out-planting of jack pine and red pine at Coniston and Whitefish.

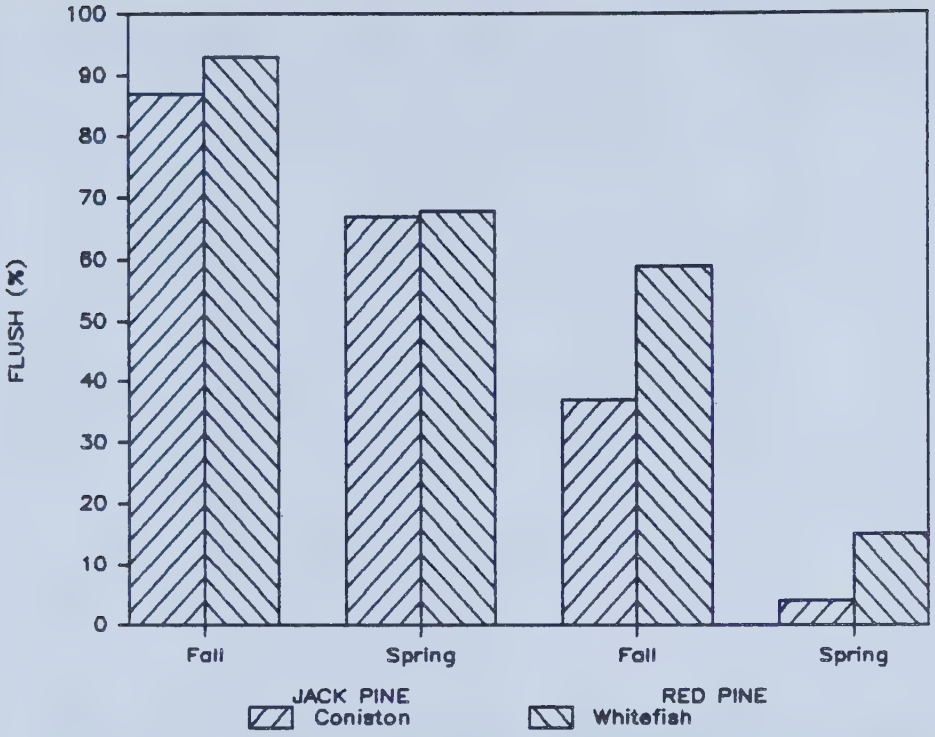

Fig. 4. Percent flush, at the end of the 1985 growing season following fall and spring out-planting of jack pine and red pine at Coniston and Whitefish.

NATIVE GRASSES IN RECLAMATION: WHAT THEY CAN AND CANNOT DO*

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ABSTRACT

Three test plots (one at Caw Creek Ridge and two at the Cadomin mine site) were established to evaluate the fitness of selected native and agronomic grass species to disturbed alpine and subalpine environments in the Eastern slopes of the Rocky Mountains in Alberta. Included in the study were the selected lines of nine native and four commercially available grass species. The alpine test plot was established on unamended spoil while the subalpine plots were established on both raw spoil and spoil capped with topsoil. Maintenance fertilization terms of from one to four years duration were also assessed to estimate fertilization requirements as a function of species and topsoil treatment.

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

INTRODUCTION

Surface mining, mineral exploration, oil and gas development, forestry, recreation and transportation disturb extensive areas in the Mountains & Foothills. These are the headwaters of Alberta's principal watersheds and the mountain streams are valuable fisheries. Therefore, erosion control is the initial objective of most land reclamation programs. The natural rate of recovery of these distrubed areas by plant colonization and succession is extremely slow and may require many decades or even centuries.

In many cases topsoil can be removed and replaced over mine spoil to enhance its plant growth potential. In other cases there is no salvageable topsoil and nutrients must be added by fertilization.

Some commercially-available agronomic grasses grow well over much of the Mountain and Foothill environment. However, these species do poorly on exceptionally harsh sites. These include alpine and upper subalpine areas, sites with unamended coarse spoil, high wind and sunlight exposure. In 1976, D.G. Walker of the University of Alberta, proposed to develop selected high elevation grasses for reclamation purposes. The proposal was supported by the Alberta Government and Parks Canada. The objective was to develop native grasses which would provide erosion control and forage on harsh sites with minimal management (e.g. fertilization, reseeding, surface amendment). Wild grasses were initially selected on their ability to invade Alpine and Subalpine disturbances. Specimens were then grown near Edmonton and selected on the basis of their cultural attributes: seed production and viability, disease resistance, vigor and uniformity of maturity.

By early 1979 this program had produced nine selected lines of native grass species. To ensure that the selected lines had not lost their tolerance to high-elevation conditions in the process of selection, a series of test plots was established:

1) to evaluate the fitness of selected lines of various native grass species to Alpine and Subalpine environments in the Eastern slopes of Alberta,

2) to study the response of native grass species to the application of fertilizer, and

3) to compare the performance of the native grasses and commonly used agronomic grasses.

MATERIALS AND METHODS

The plots were established on September 14-17, 1979. One test plot involving no topsoil treatment was established at Caw Creek Ridge (Alpine) and two test plots, one with and another without topsoil treatment, were established at the abandoned Cadomin Mine site (Subalpine).

DESCRIPTION OF STUDY AREAS

a. Caw Creek Ridge (Alpine) The study area is located near Grande Cache, Alberta (NW 1/4 35-58-10 W6M) at an elevation of 1901 m and was once accessible by four-wheel drive vehicles under favourable weather conditions. The site is a former drilling pad and consists of a flat surface covered with broken and recently weathered shale. Rocks and pebbles of varying sizes dominate the site. The study area has been fenced in order to minimize disturbance. The soil sample taken from the area was analyzed by the Alberta Agriculture, Soil Testing Laboratory and the results are presented in the Appendix.

b. Cadomin Mine Site (Subalpine) The study area is located in the Rocky Mountain Foothills of west-central Alberta (S 1/2 32-46-23 W5M) at an elevation of 1675 m. This former open-pit coal mine is 1.6 km south- east of Cadomin, Alberta and is accessible by four-wheel drive vehicle. The site is characterized by flat-topped spoil-heaps consisting mainly of sandstone, silstone, and shale overburden. The study area is fenced.

Experimental Design The effects of four fertilization regimes on the growth of thirteen species were tested in a 4 x 13 factorial randomized block design with three replications. The same experimental design was implemented at both Caw Creek Ridge and Cadomin mine sites (see Appendix for details of experimental design and plot layout).

A commercial brand of inorganic fertilizer (Diammonium phosphate) yielding 18-46-0 was applied in early June from 1980 through 1983 to all three test plots. The rate of fertilization was 150 kg/ha or 15 g/m^2. The fertilizer was applied to an area of about 15 cm on either side of (1 m long) furrows. Maintenance fertilizer application periods of from one to four years comprised the fertilizer treatments. By 1983, the fourth year of the study, all four fertilizer treatments had been applied.

The native seed used in the experiment was grown at the Genetics Field Laboratory of the University of Alberta at Ellerslie and harvested in 1978. With the exception of poa interior, the seed sample of each of the native species used was composed of a mixture of two or more improved lines (multiline) selected in 1978 (for sources of different lines, see Appendix). The four commercial varieties of grass species used in the study were obtained from local seed distributors.

Seeds were sown by hand in a 1 m long furrow. The depth of seeding varied from 1-2 cm. Immediately after planting, seeds were covered with soil. Each furrow was marked with a metallic label indicating the randomization code numbers. Information on seeding rate, weight of 1000 seeds and seed germination percentages of various grass species used i the study is given in the Appendix.

The grass species were seeded in September 1979 and the performance of these species was assessed in mid-August from 1981 to 1983. In assessing species performance, three parameters were of interest: 1) Aerial Cover, 2) Flowering and 3) Seed Head Shattering. Aerial Cover was estimated using a horizontal $1m^2$ grid with 10 cm^2 divisions. The seeds had been planted in 1m long furrows to minimize interplot competition and fertilizer movement. Therefore the data reflect the degree to which each species colonized first the furrow and then the surrounding area. The following formula very roughly translates the Aerial Cover data into % ground cover:

$$\% \text{ Cover} = (100\ cx)\ (500\ vld)^{-1}$$

where: c = Aerial Cover (cm^2)
x = Seeding Rate (Seeds/Linear 100 cm)
d = distance between drill rows (cm)
l = Plot length (cm)
v = Seed Viability (%)

The constant 500 represents the seeding rate (per linear meter) used in this study.

Unless a species produces propagules on a site it will ultimately die out. High elevation sites with their short growing seasons restrict reproduction in may commercial grass species. As part of species performance assessment, flowering and shattering were recorded for each plot during August 13-15 of 1981, 1982 and 1983.

RESULTS

Extremely windy conditions combined with the coarse spoil to contribute to the poor establishment of the grasses at the subalpine no topsoil site. This site was chosen because of its harshness and the results therefore, are not representative of grass establishment on most untopsoiled mountain spoils. Winds of 150 km/hr have been recorded at the site and in the year after seeding, the surface had deflated leaving a pavement of ironstone and shale fragments. Individual ironstone fragments roughly 1 cm^3 and larger, had in fact, been blown up to halfway (6m) across the adjacent topsoiled plot. Presumably much of the seed traveled even farther. On the finer textured alpine and topsoiled subalpine sites, seedling establishment was generally effective and no wind erosion was evident.

1. Aerial Cover

Two key objectives of revegetation in the mountains are erosion control and forage production. The former is the first priority so each species was rated on its capacity to quickly generate ground cover. Species selection and fertilizer regime were both found to significantly affect cover. The species by fertilizer interaction was significant only at the alpine site suggesting that in the subalpine the native and agronomic species responded similarly to fertilization (Table 1).

(a) Species Selection. The native Agropyrons: trachycaulum, latiglume, dasystachyum, and subsecundum consistently produced the most aerial cover. The other natives: Tristeum spicatum, Poa interior, Poa alpina, Festuca saximontana and Deschampsia cespitosa fared poorly on the sub- alpine sites. However, Poa interior, Poa alpina and Festuca saximontana were among the best performers at the alpine site (Figures 1, 2).

Among the agronomic grasses Festuca rubra (c.v. Boreal) and Agropyron trachycaulum (c.v. Revenue) were superior in terms of cover production.

(b) Fertilization. Fertilization had a strong effect at each site. The effect of the yearly fertilization was cumulative on the no topsoil sites but seems to have levelled off after three years at the topsoiled site (Figure 3). The fertilization by species interaction demonstrates this clearly (Figures, 4, 5, 6). Also, die-back on the no topsoil sites occurred annually after cessation of fertilization while on the topsoiled site growth continued to be strong after maintenance fertilization was terminated (Figure 7).

Table 1 - Analyses of Variance for Aerial Cover Data

n	Source of Variation	Degrees of Freedom	'F' Test Subalpine No Topsoil	Subalpine Topsoil	Alpine
3	Reps	2			
13	Spp.	12	9.0*	28*	3.3*
4	Fert.	3	12.9*	8.6*	62.7*
	SXF	36	1.4	1.4	2.4*
	Error	102			
156	Total	155			

* = Significant at 95% Confidence Level

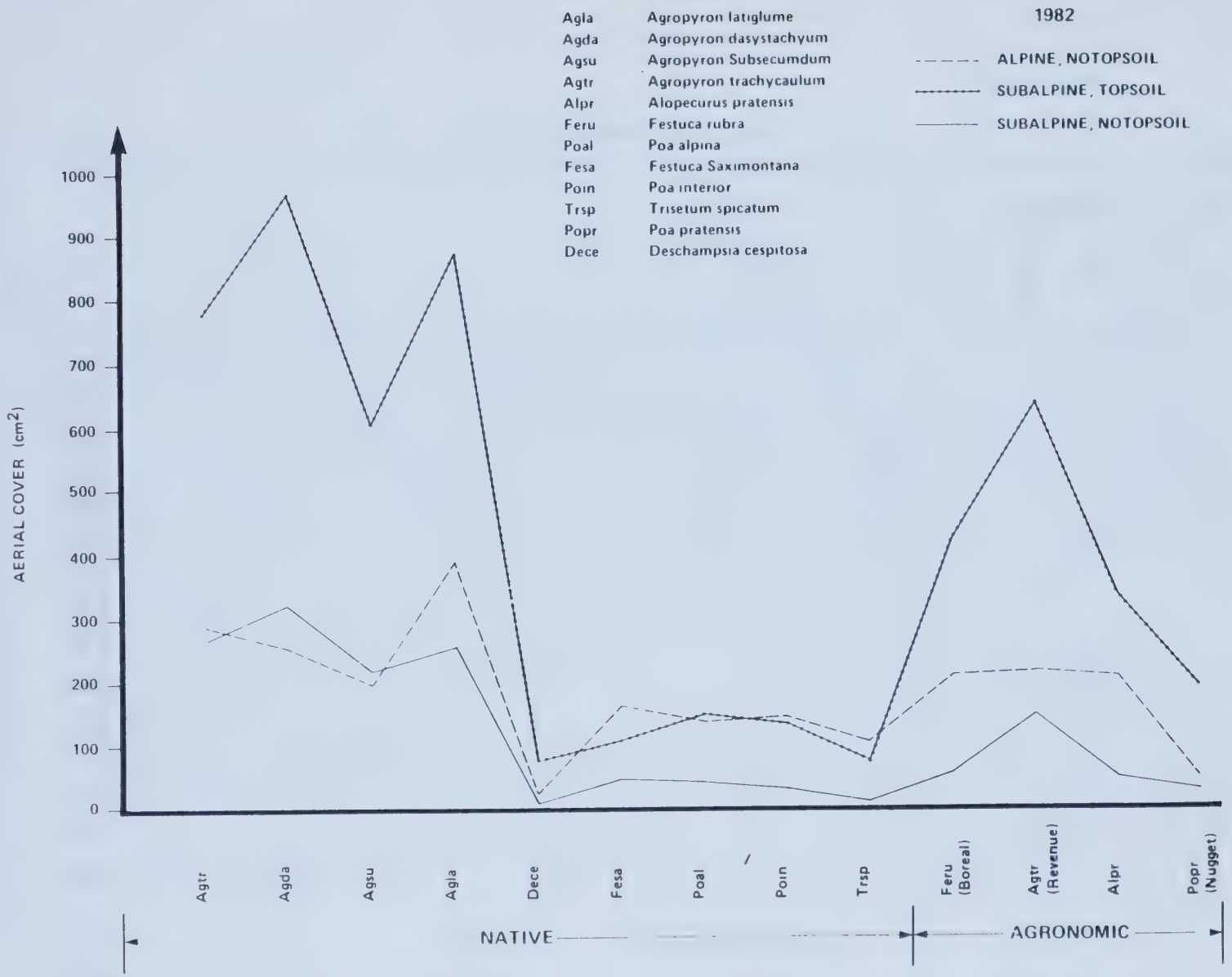


Figure 1. Aerial Cover Development by the 13 Grasses in 1982

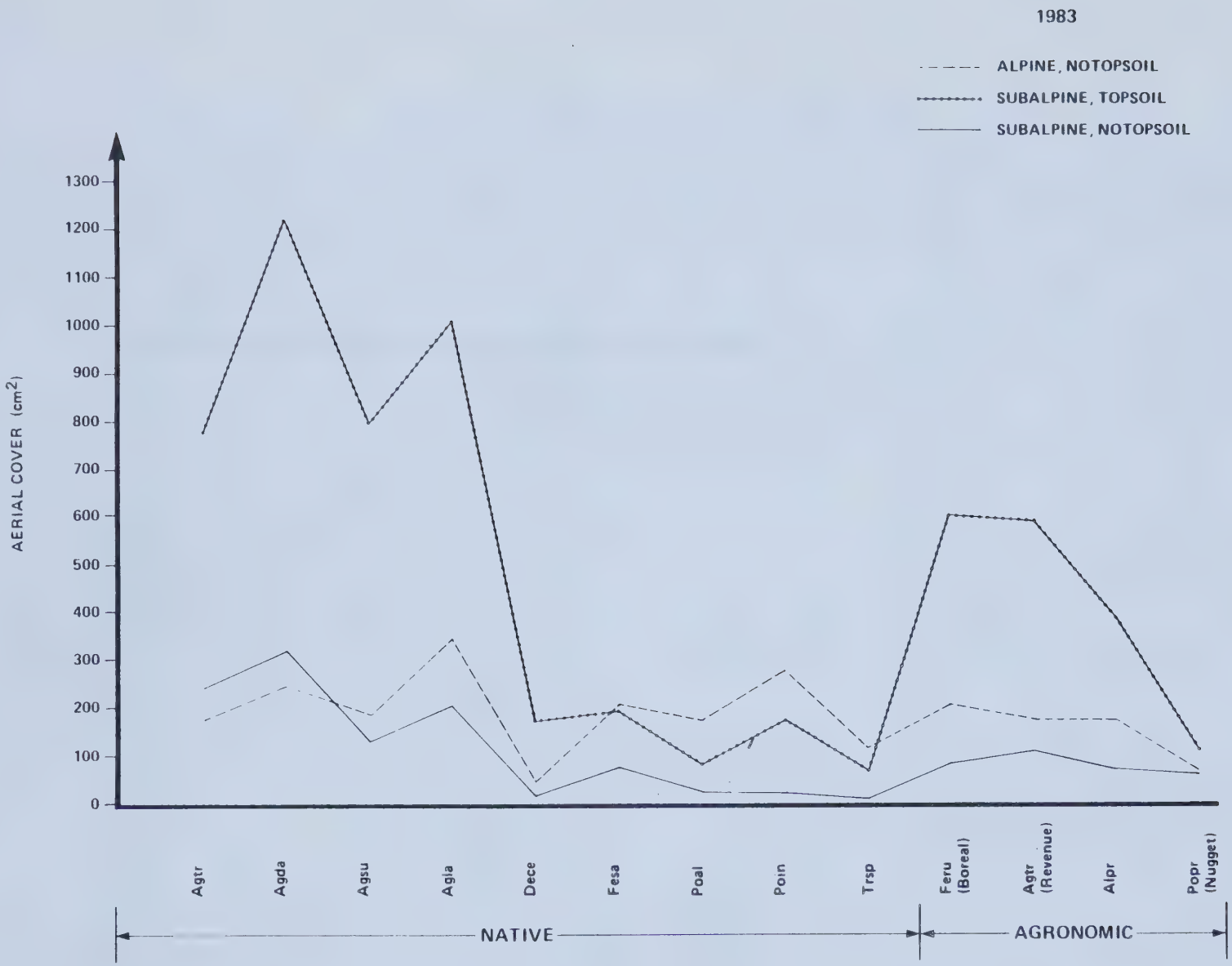
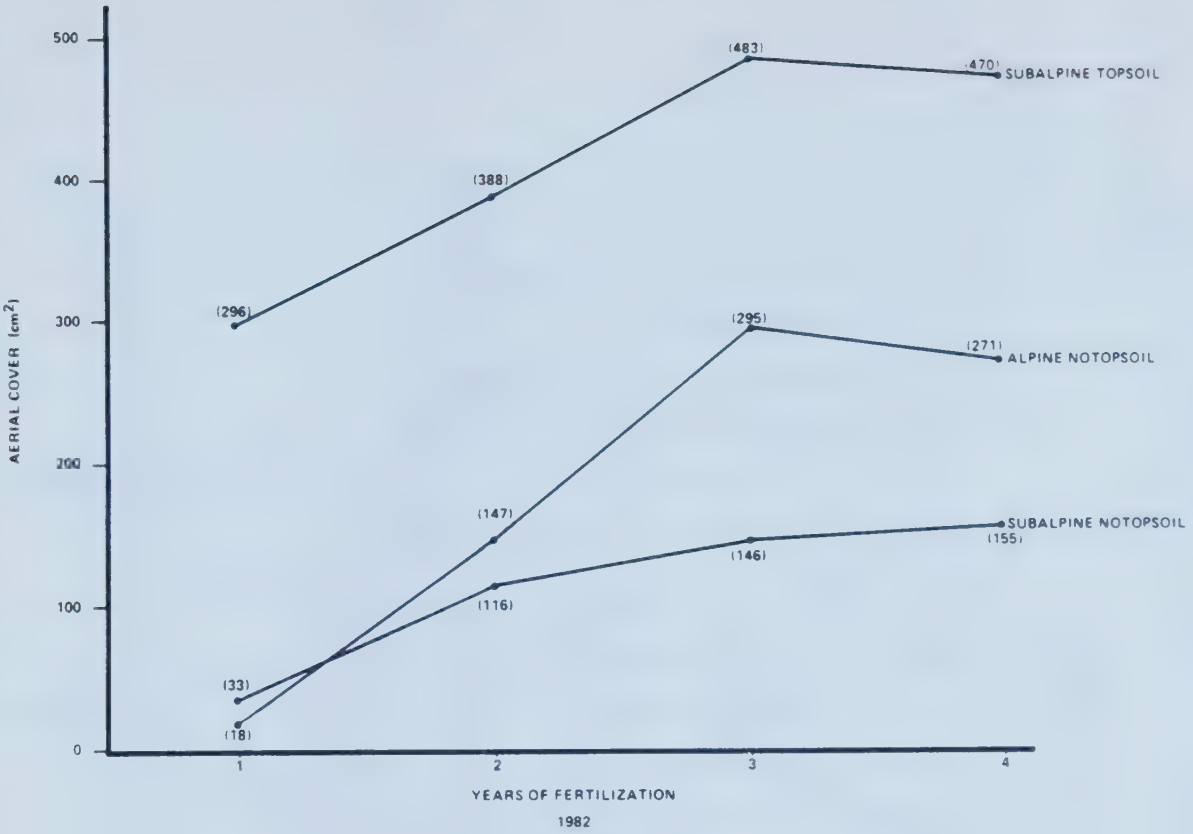


Figure 2. Aerial Cover Development by the 13 Grasses in 1983



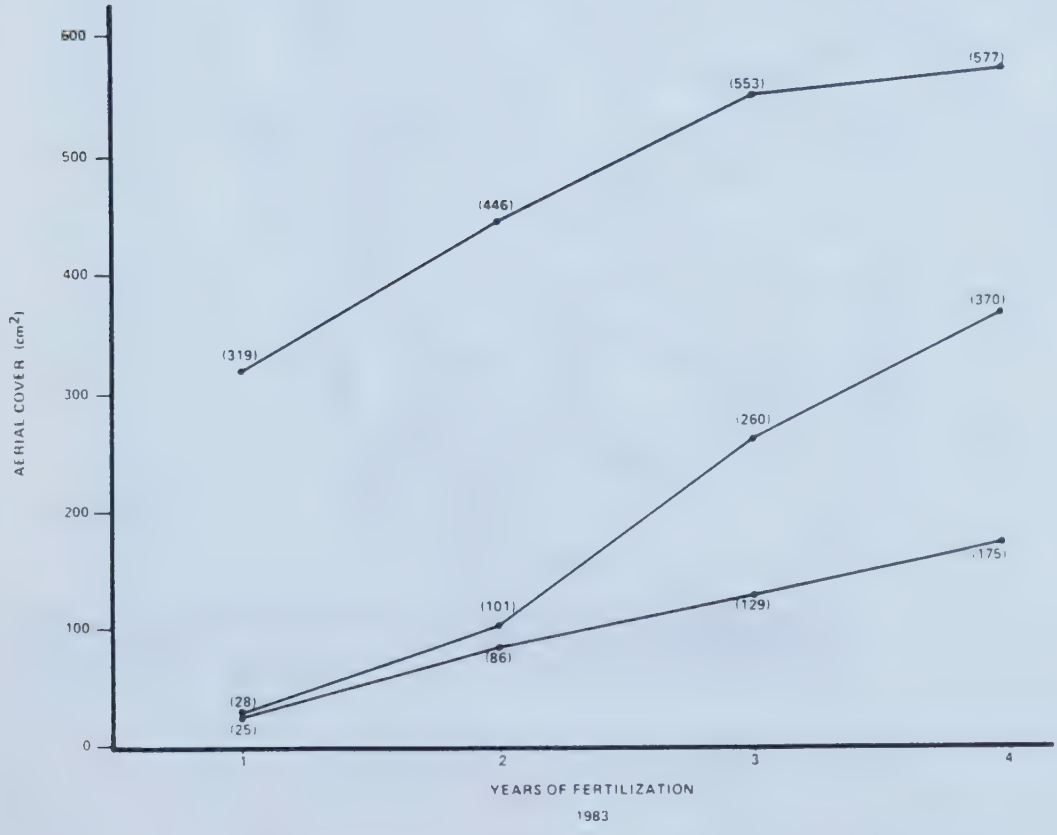


Figure 3. The effect of Fertilization, Site and Topsoil on Aerial Cover in 1982 & 1983. The Initial Fertilization Occurred in 1980

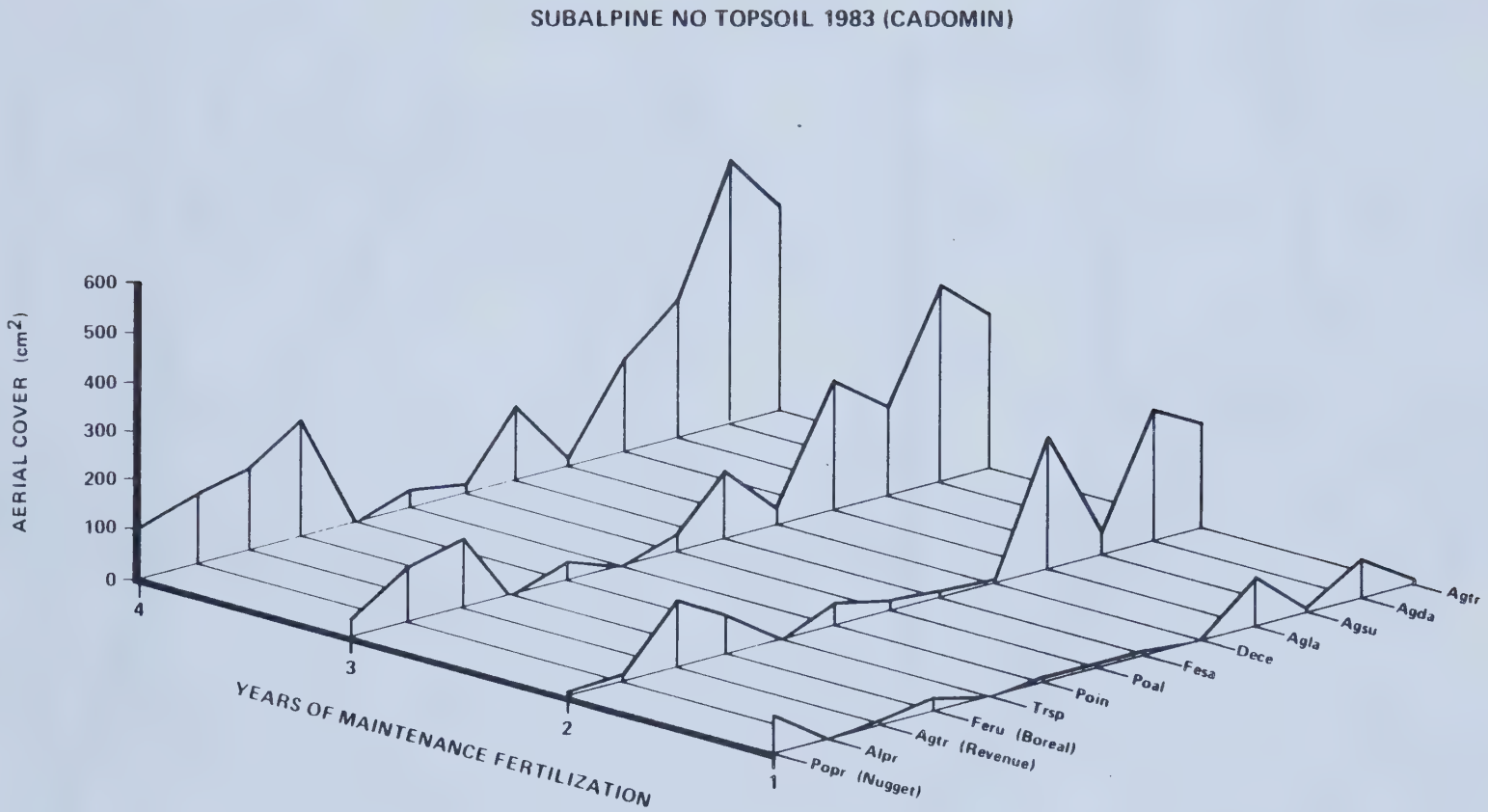


Figure 4. The Response of 13 Grass Species to One to Four Years of Maintenance Fertilization at the Subalpine No Topsoil Site

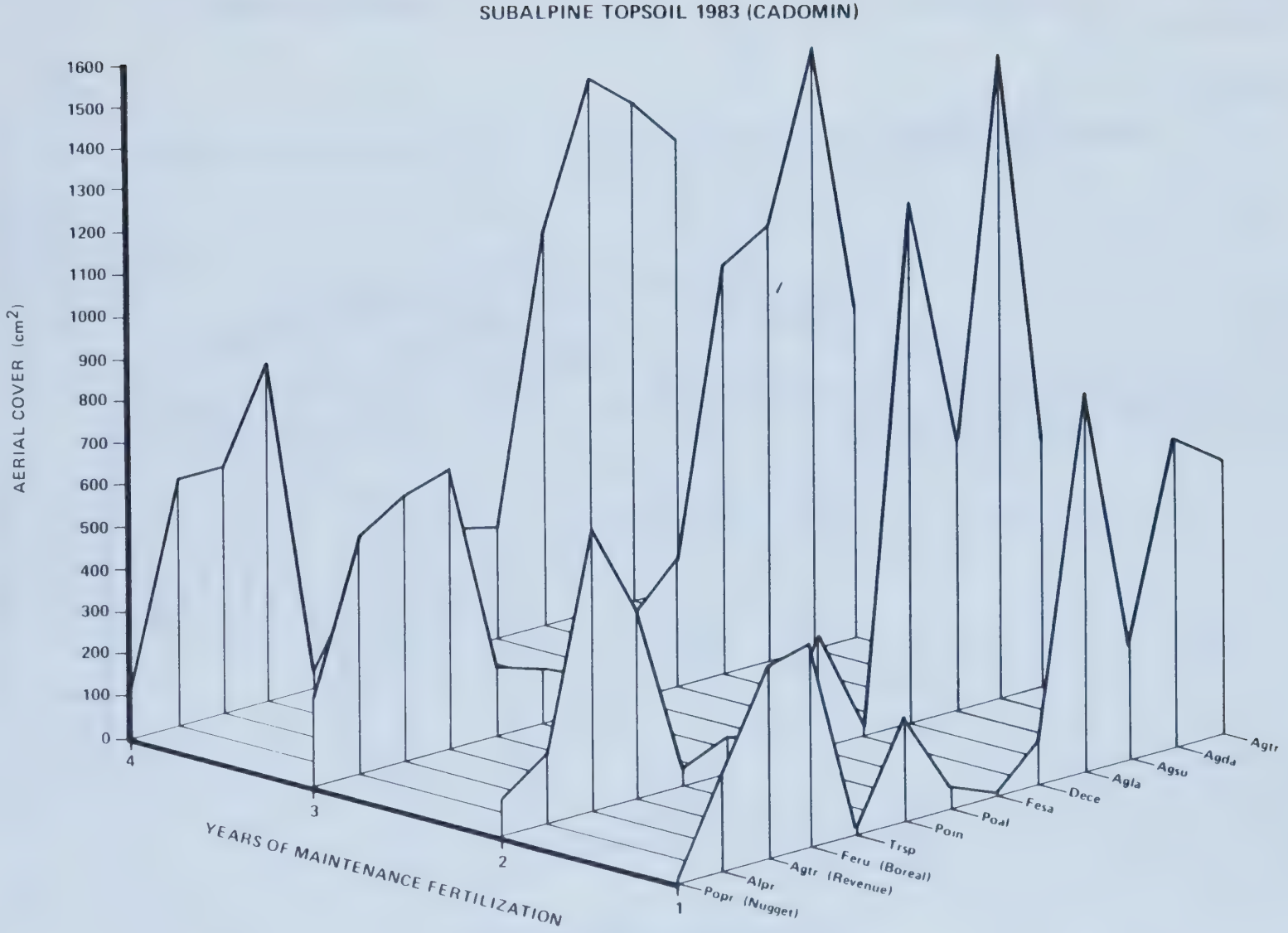


Figure 5. The Response of 13 Grass Species to One to Four Years of Maintenance Fertilization at the Subalpine Topsoiled Site

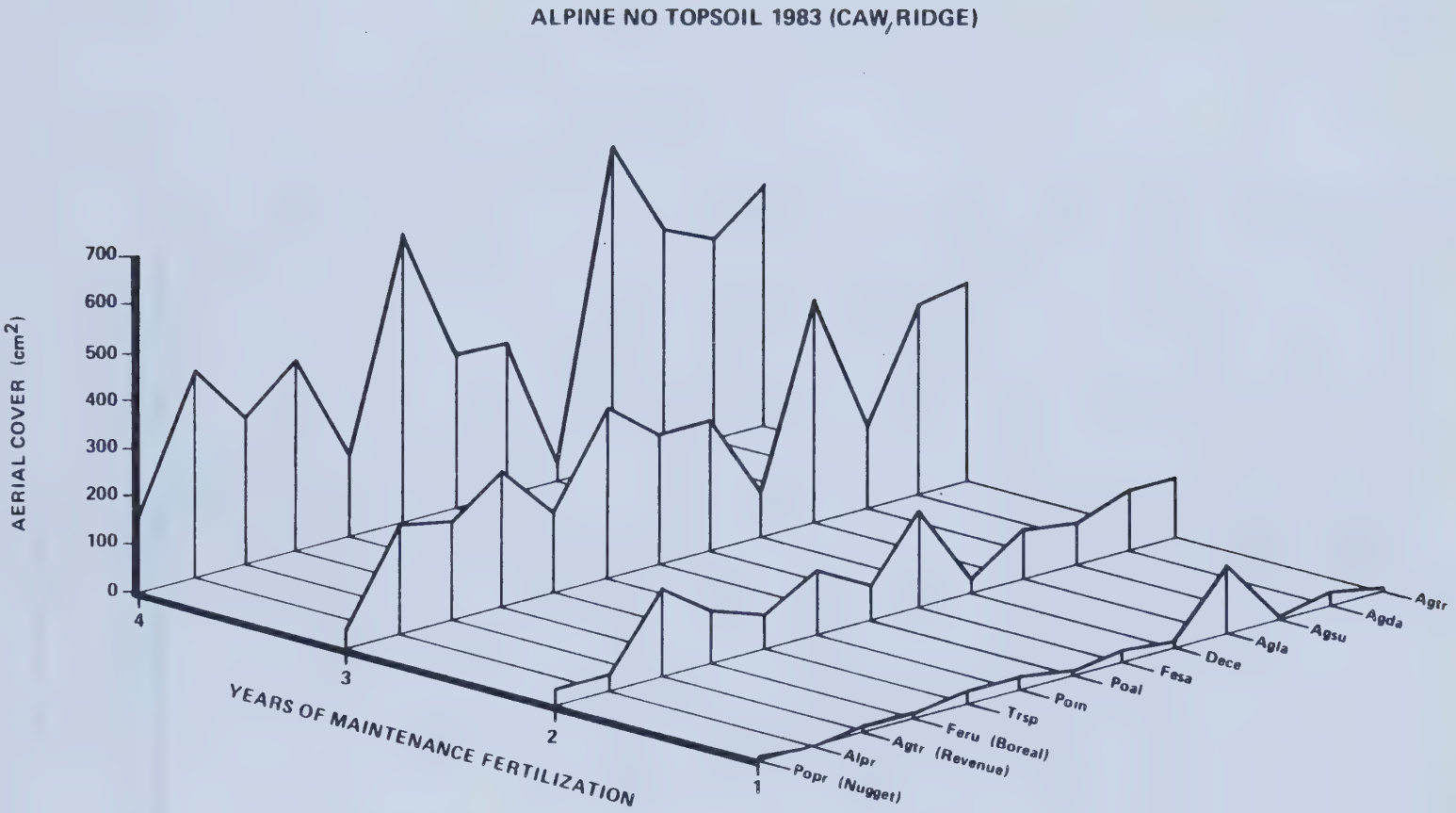


Figure 6. The Response of 13 Grass Species to One to Four Years of Maintenance Fertilization at the Alpine Site

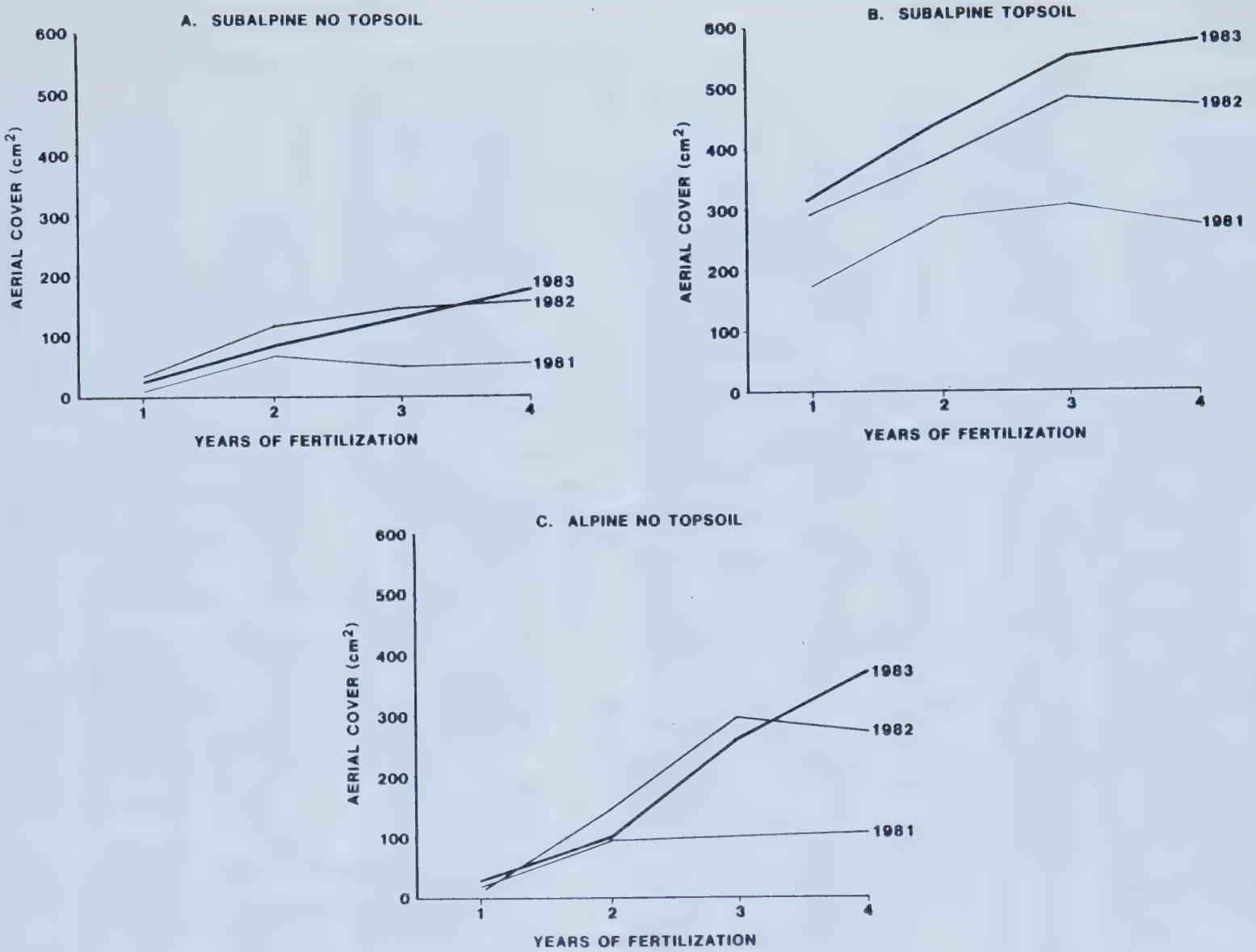


Figure 7. Aerial Cover on the Three Test Sites Measured from 1981 to 1983 as a Function of Maintenance Fertilization

2. Flowering and Shattering

The tendencies for a grass to flower and particularly to undergo seed head shattering by August were regarded as indicators of its reproductive potential. Reproduction by seed will be necessary by all of the test species except for the rhizomatous Agropyron dasystachyum. There was no attempt to collect and test the viability of seed produced on the plots.

Agropyron latiglume and A. trachycaulum consistently displayed high rates of flowering and shattering in the subalpine while Agropryon trachycaulum (c.v. Revenue) shattered in only 8% of the subalpine plots.

Although many of the small-seeded species did not establish during the first year the surviving individuals at Cadomin showed a strong tendency to flower and shatter (e.g., Festuca saximontana, Poa alpina, Poa interior and Deschampsia cespitosa). Only Agropyron dasystachyum failed to shatter on any site. This was in part compensatsd by its strong tendency to propagate via rhizomes. Other species with low reproductive potential were Agropyron subsecundum and Agropyron trachycaulum (c.v. Revenue). All species except Agropyron dasystachyum flowered at the alpine site. However, only Agropyron latiglume, Deschampsia cespitosa, Festuca saximontana, Poa alpina, Poa interior and Alopecuris pratensis had shattered by mid-August (Table 1).

CONCLUSIONS

Species Selection. Agropyron latiglume was perhaps the best grass tested since it was among the top cover producers on all sites and it showed excellent reproductive potential. Agropryon trachycaulum was also excellent though it never shattered in the Alpine. Agropyron dasystachyum and Agropyron subsecundum produced good cover but had low reproductive potential. In the case of Agropyron dasystachyum this was compensated by its strong rhizomatous tendency.

The other native grasses clearly had establishment problems at the subalpine site. Those plants which germinated and survived, however, continued to increase in cover and displayed strong reproductive potential.

None of the Agronomic Grasses produced as much cover as the native Agropyrons on the subalpine sites. The Agronomic and native grasses generated similar cover levels on the alpine site though the native grasses had a greater reproductive potential.

Based on cover development and reproductive potential of the tested grasses, three conclusions may be drawn regarding species selection:

Table 2 - Incidence of Flowering as a Function of Site, Topdressing and Species (% of Plots with Plants in Flower: % of Plots with Seeds Shattering) in the 3rd and 4th years of the experiment.

	SUPALPINE				ALPINE	
	Topsoil		No Topsoil			
	1982	1983	1982	1983	1982	1983
Agropyron trachycaulum	100:92	100:25	75:42	75:42	42:0	58:0
A. dasystachyum	92:0	83:0	58:0	42:0	0:0	0:0
A. subsecundum	100:0	100:17	75:8	75:25	8:0	8:0
A. latiglume	100:92	100:100	83:83	100:00	67:8	58:0
Deschampsia caespitosa	50:50	83:83	0:0	8:8	0:0	33:33
Festuca saximontana	75:50	75:66	50:50	50:50	67:50	83:0
Poa alpina	92:83	100:100	33:33	42:42	58:25	91:0
Poa interior	83:75	83:83	8:8	33:33	67:0	75:8
Trisetum spicatum	33:33	50:50	8:8	8:8	33:0	75:0
Festuca rubra (Boreal)	92:25	91:91	42:8	25:25	25:0	66:0
A. trachycaulum (Revenue)	100:0	100:8	58:8	50:0	0:0	0:0
Alopecurus pratensis	83:50	75:66	8:8	17:17	33:8	17:0
Poa pratensis (Nugget)	75:58	83:83	33:33	17:17	8:0	50:0

1. On subalpine sites the native Agropryon trachycaulum, A. subsecundum and A. latiglume would be the best grasses for reclamation.

2. On alpine sites Poa alpina, Festuca saximontana, and Agropyron latiglume would be the best.

3. The Agronomic grasses Festuca rubra, Agropryon trachycaulum (c.v. Revenue) and Alopecuris pratensis all provided good levels of cover on the subalpine and alpine sites. The reproductive potential of Agropryon trachycaulum (c.v. Revenue) was almost nil, however, and Alopecuris cover dropped off sharply two years after maintenance fertilization stopped. Festuca rubra, therefore, is the recommended agronomic grass both in the subalpine and alpine.

Fertilization

Plant cover was enhanced by maintenance fertilization. Except for species which failed to become established, cover was invariably highest on plots fertilized in the assessment year. On non-topsoiled sites dieback was a common occurrance in the years following fertilizer withdrawal. This tendency was general though it appeared most strongly pronounced in Alopecuris pratensis and Agropyron subsecundum. The effect of fertilizer withdrawal was not observed in many species for two years. The trend, on unamended spoil without legumes however, seems to be continuous and downward for both native and agronomic grasses.

Topsoil

No dieback occurred on topsoiled plots. Cover continued to increase even on plots which had only been fertilized once. This suggests that after the initial fertilization topsoiling provides adequate nutrients for the establishing grass cover. One or two years of fertilization would be recommended to accelerate the rate of cover development and to minimize erosion. Afterwards no further fertilization should be required.

RECOMMENDATIONS

Some of the native grasses in this study appear to have an important role to play in the revegetation of subalpine and alpine disturbances. Their primary advantage appears to be through their reproductive strategy: early flowering, seed set and dispersal. The probability of successfully establishing native grass generations subsequent to initial seeding is likely to be higher than with the available agronomic grasses in the alpine and upper subalpine regions.

Other physiological responses appear to place the native and agronomic grasses on a par. Both study groups were capable of persisting for five years given adequate nutrients. Both groups expanded their area coverage during the test period.

Neither the native nor agronomic grasses are likely to perform well in nutrient poor mine spoil without proper management. Both groups responded to maintenance fertilization and both groups suffered severe dieback after fertilization was discontinued. This confirms the need to ensure those elements of the reclamation plan which will contribute to an adequate soil nutrient supply: soil replacement and strong legume establishment.

Appendix 1

AGRICULTURAL SOIL AND FEED TESTING LABORATORY

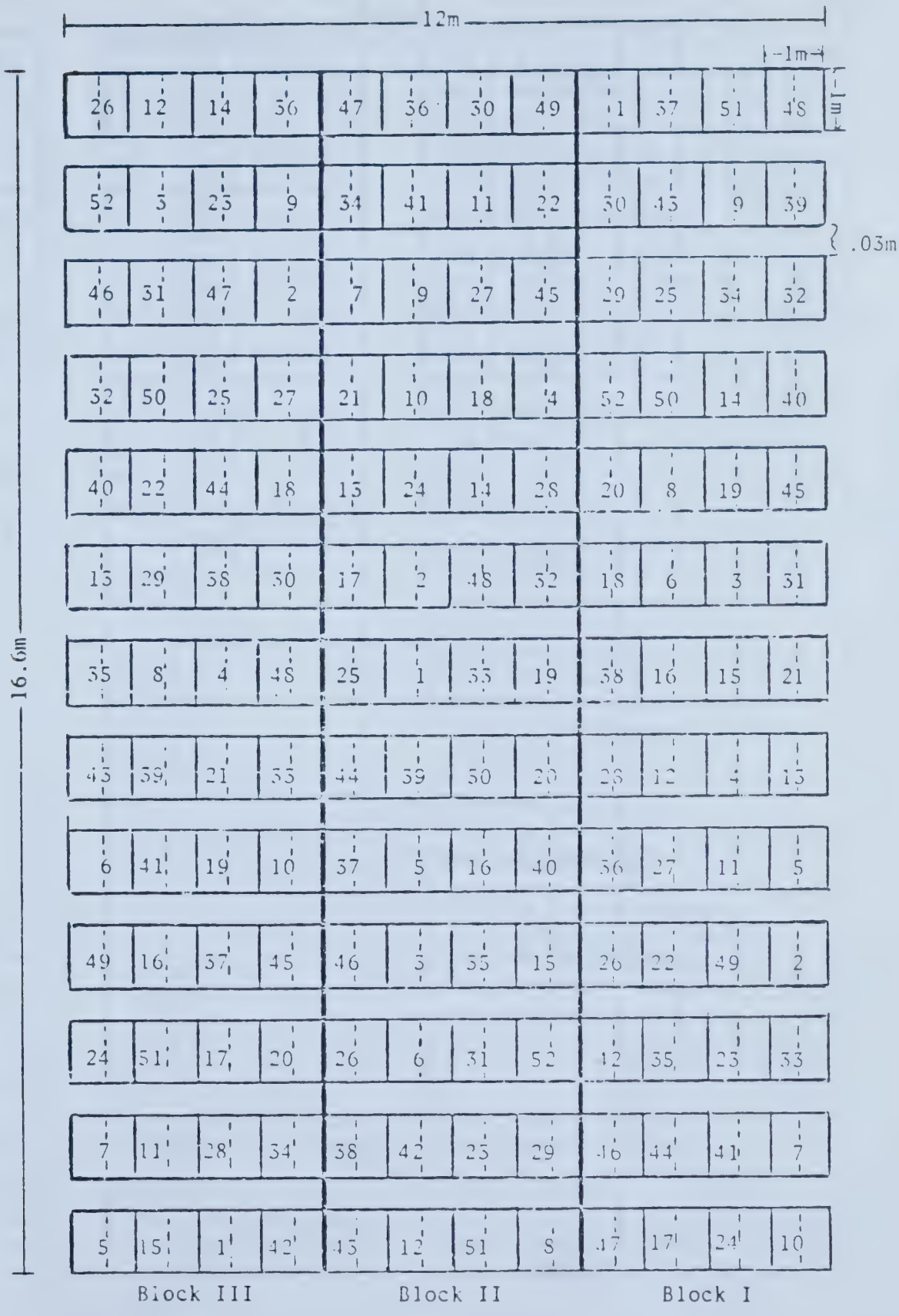
TEST RESULTS ON SOIL SAMPLES

B 45500
Date: 1/2/80

Plot No.*	(N)	(P)	(K)	(Na)	(S)	(ph)	Conductivity mmhos.	Sulfate SO_4	Org. Matter	Free Lime $CaCO_3$	Texture
1	2	1	178	L-	M-	8.5	0.2	---	M	---	2
2	5	4	145	L-	L+	7.6	0.2	---	L	---	2
3	2	1	112	L-	M-	8.1	0.2	---	L+	H-	3

* 1 Cadomin Mine Site Overburden
2 Cadomin Mine Site Topsoil
3 Caw Creek Ridge Soil Sample

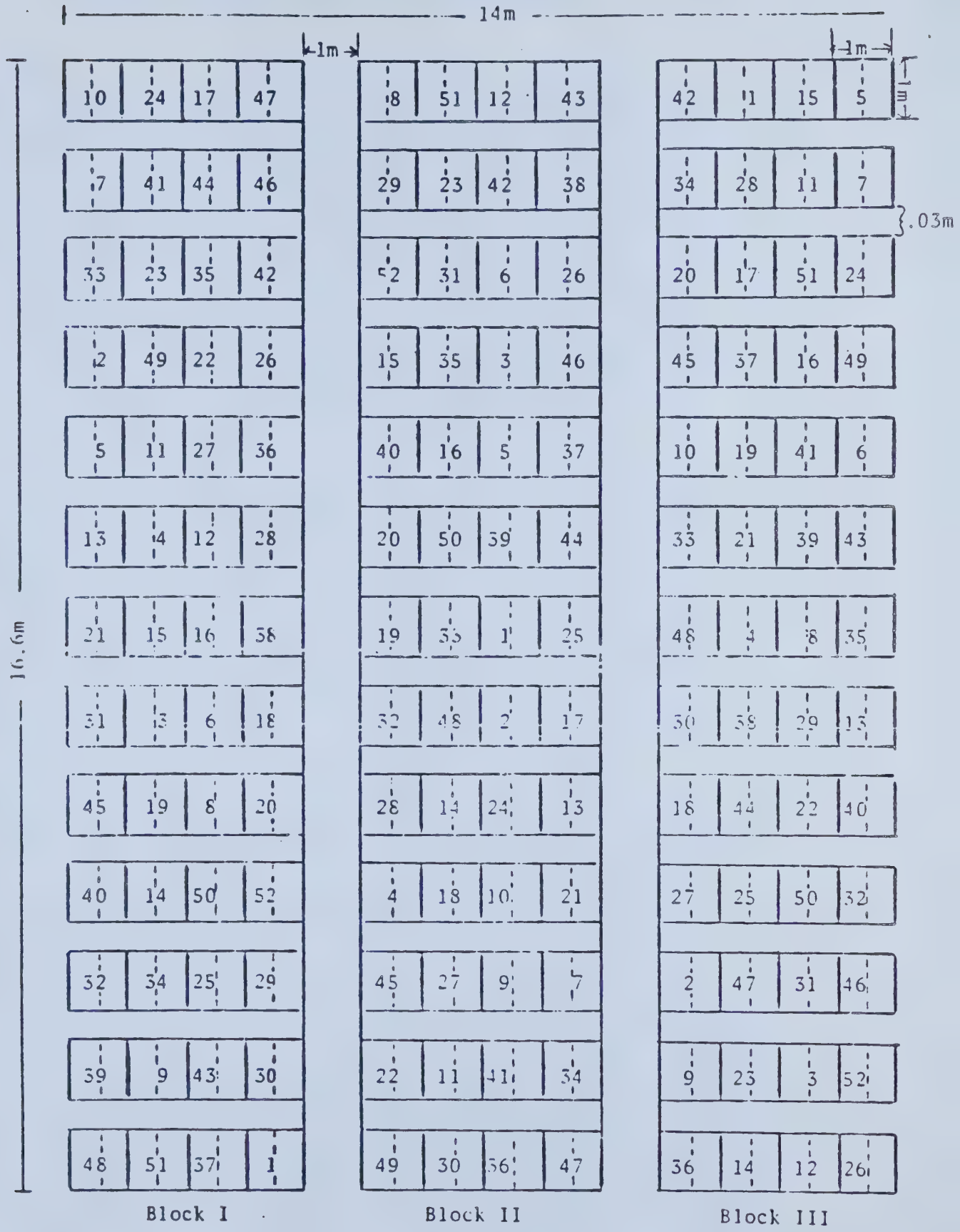
Experimental design used for establishing test plots at Caw Creek Ridge and Cadomin.



NOTE: 1) Broken lines within $1m^2$ plots represent direction of furrows.

2) See Key to Species (Tables 2-4) for explanation of code numbers used in different blocks.

Experimental design used for establishing test plots at Cadomin. The same layout was used on raw overburden and on topdressed overburden.



NOTE: 1) Broken lines within $1m^2$ plots represent direction of furrows.

2) See Key to Species (Tables 2-4) for explanation of code numbers used in different blocks.

Appendix II Cont'd.

Randomization

Code	Species/Years of fertilization
1	1/1
2	2/1
3	3/1
4	4/1
5	5/1
6	6/1
7	7/1
8	8/1
9	9/1
10	10/1
11	11/1
12	12/1
13	13/1
14	1/2
15	2/2
16	3/2
17	4/2
18	5/2
19	6/2
20	7/2
21	8/2
22	9/2
23	10/2
24	11/2
25	12/2
26	13/2
27	1/3
28	2/3
29	3/3
30	4/3
31	5/3
32	6/3
33	7/3
34	8/3
35	9/3
36	10/3
37	11/3
38	12/3
39	13/3
40	1/4
41	2/4
42	3/4
43	4/4
44	5/4
45	6/4
46	7/4
47	8/4
48	9/4
49	10/4
50	11/4
51	12/4
52	13/4

Species Code

Selected Lines of:

1. Agropyron trachycaulum
2. A. dasystachyum
3. A. subsecundum
4. A. latiglume
5. Deschampsia caespitosa
6. Festuca saximontana
7. Poa alpina
8. Poa interior
9. Trisetum spicatum

Commercial Lines of:

10. Festuca rubra (Boreal)
11. A. trachycaulum (Revenue)
12. Alopecuris pratensis
13. Poa pratensis (Nugget)

Appendix III Grass species seeded at Caw Creek Ridge and Cadomin

Species Code	Genus and Species	Source	Approx. No. of seeds/1m furrow	1000 seed wt. (g.)	% Germination (lab. test)
	Native Species				
1	**Agropyron trachycaulum**	Multiline Selection (1978) derived from: Grassy Mountain, Waterton Flats, Smoky River, Barnaby Ridge, Mountain Park, Sheep River	500	4.28	92
2	**Agropyron dasystachyum**	Multiline Selection (1978) derived from: Kootenay Plains, Sheep River, Mount Stearn, Cat Creek, Ya Ha Tinda, Athabasca Ranch	500	4.00	93
3	**Agropyron subsecundum**	Multiline Selection (1978) derived from: Greenock Mountain, Athabasca Ranch, Smoky River, Rock Lake	500	4.48	92
4	**Agropyron latiglume**	Multiline Selection (1978) derived from: Mountain Park, Caw Creek Ridge	500	4.80	91

Appendix III (cont'd)

Species Code	Genus and Species	Source	Approx. No. of seeds/lm furrow	1000 seed wt. (g.)	% Germination (lab. test)
5	**Deschampsia caespitosa**	Multiline Selection (1978) derived from Marmot Parkers Ridge Beartooth Hwy., Montana	500	0.30	85
6	**Festuca saximontana**	Multiline Selection (1978) derived from: Mountain Park Coal Valley Pyramid Lake	500	0.72	91
7	**Poa alpina**	Multiline Selection (1978) derived from: Grassy Mountain Coal Valley Barnaby Ridge Mountain Park Snow Creek Sunshine	500	0.56	55
8	**Poa interior**	Selected Line (1978) derived from: Whistlers Mountain	500	0.36	79
9	**Trisetum spicatum**	Multiline Selection (1978) derived from: Cat Creek Coal Valley Grassy Mountain	500	0.24	85

Appendix III (cont'd)

Species Code	Genus and Species	Source	Approx. No. of seeds/1m furrow	1000 seed wt. (g.)	% Germination (lab. test)
	Commercial Lines				
10	**Festuca rubra**	Commercial variety: Boreal	500	1.20	74
11	**Agropyron trachycaulum**	Commercial variety: Revenue	500	4.20	92
12	**Alopecuris pratensis**		500	0.80	89
13	**Poa pratensis**	Commercial variety: Nugget	500	0.50	

THE RECOVERY OF EARTHWORM POPULATIONS AFTER OPENCAST COAL MINING *

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ABSTRACT

The changes in earthworm populations were assessed over three years on three restored sites of initial age 0, 2, and 5 years after restoration. Numbers and biomass were found to increase exponentially during the first eight years after restoration. Comparison of the populations at the edge and centre of sites suggested that migration into the site from adjacent undisturbed areas played no significant part in the recovery of populations.

INTRODUCTION

Examination of earthworm populations before, during, and after opencast coal mining indicates that soil movement, and particularly compaction by machinery, causes a great reduction in earthworm populations (Martin, 1987).

To assess the subsequent recovery of populations three sites were examined over four years to give the ageing sequence from 0-8 years. The sites chosen were as similar as possible, to reduce the variability in other factors.

Little detailed work has been done on sites of these ages. Pringle (1958) found no earthworms on a two year old site, whereas Thompson (1958) found populations of up to 78 m^{-2} on four year restored sites, with most having around 37 m^{-2}. Brook and Bates (1960) considered restored populations to be equivalent to controls after four years, with populations of 15 to 176 m^{-2}. More recently Rushton (1986) found no worms on a newly restored site and 20 m^{-2} on a two-year old restored site. 15-year restored sites were dominated by A.longa and A.chlorotica, L.terrestris only being found on one such site with an established sward. Similarly Standen et al (1982) found no earthworms one year after restoration, small numbers on two year old sites, principally A.chlorotica, and 33 m^{-2} on 11 year old sites.

* Presented at the Twelfth Annual Meeting , Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987

METHOD

The work was carried out on three restored sites, Godkin, Whitehouse and Shipley, in Derbyshire, England, which had been restored for 0, 1.75 and 4.75 years respectively. Sampling was carried out between 1983 and 1986, mainly in the spring. The formalin method was used (Raw, 1959), with 30 stratified random samples from the centre of each site. Populations at the boundary were sampled by five parallel transects approximately 10 m apart across the site boundary into the restored area, with each transect containing at least nine quadrats 15 m apart.

As the range of counts and weights was large and contained many low values for the younger sites, a $\log_{10}(n+1)$ transformation was applied to normalise the distribution. This data was used for all t-tests, but for ease of comparison the untransformed data is given in the text.

RESULTS

Earthworm populations from the centre and boundary of each site are given in Tables 1 and 2. Initial populations were 0.8 m^{-2} and 0.2 g m^{-2} at Godkin, 1.3 m^{-2} and 0.7 g m^{-2} at Whitehouse, and 59.3 m^{-2} and 28.5 g m^{-2} at Shipley.

Numbers and biomass at Whitehouse were lower than at Godkin at the equivalent age ($P<0.01$ and $P<0.001$), mainly due to the large number of L.rubellus found at Godkin in 1986. There was no significant difference in the populations of A.caliginosa, A.chlorotica, and A.longa ($t=1.11$, 1.67 and 1.50). The initial population at Shipley was not significantly different from that at Whitehouse.

Regression of earthworm numbers from the site centres against site age since restoration indicated that site age had a significant effect on biomass ($P<0.001$) accounting for 92.5% of the variance (Figure 1). There was no significant improvement to the model by allowing each site to have its own intercept, or slope and intercept (Table 3).

Similarly for earthworm biomass the principal trend was with site age ($P<0.001$), which accounted for 89.1% of the variance (Figure 1). There was no significant improvement to the model with independent intercepts or slopes and intercepts for each site (Table 4).

The analysis was repeated on the final 30 quadrats of the transects, which were blocked to give an overall mean representative of the population at the site boundary. The rate of increase of populations at the site centre and boundary were not significantly different.

Results for individual species showed similar, though less precise, linear trends. Examination of the youngest sites suggests that this was because they became established more slowly. A.caliginosa did not occur in significant numbers until sites had been restored for three years. A.chlorotica and A.longa were rare on sites of less than four years. Subsequently the populations of these species increased rapidly.

Numbers of L.rubellus tended to increase to a peak at five years, and subsequently decreased. This species may initially benefit from the conditions on restored sites, but subsequently be displaced by other species.

Numbers of L.terrestris were variable and low. The population at Godkin in spring 1986 was comparatively high for a newly restored site. Whitehouse and Shipley had very low L.terrestris populations, and other surveys (Martin, 1987) suggested that the species is rare on sites restored for less than 15 years.

Transects

Analysis of variance of total fresh weight along the transects (Table 5) indicated that there was a significant difference between ages ($P<0.001$). In addition there was a significant linear trend with distance into the site($P<0.001$), but no significant change in this trend with age. Values for the centre of the sites were higher than expected by extrapolation of the regression, particularly for sites over three years old. Although the boundary populations were initially higher, there was no consistent difference between the means for the site boundaries and centre.

Analysis of variance of total numbers of earthworms (Table 5) indicated that there was a significant difference between the ages ($P<0.001$). In addition there were significant differences between points along the transect ($P<0.05$) and a significant linear trend with distance into the site ($P<0.01$). This linear trend differed significantly with age ($P<0.05$). However, the gradient decreased rather than increasing as expected. Again numbers at the site centre were higher than anticipated by extrapolation of the regression particularly on sites older than three years. There was no consistent difference between the populations at the boundary and centre.

DISCUSSION

Log10 earthworm biomass was found to increase linearly with age. Thus, the untransformed biomass would increase exponentially on sites up to eight-years since restoration. This suggests that either biomass is unlimited by site conditions, or site conditions are also improving.

Earthworm numbers increased in a similar fashion, but at a greater rate, the slope for site centres being 0.34 compared with 0.28 for biomass.

As the increases were exponential the period of increase is bound to be limited, and study of sites over eight-years old is likely to indicate a levelling out of population growth. Thus, given intercepts at between one and four years, overall population growth would be sigmoidal.

One might expect the earthworm populations at site edges to be higher than at the centre if the area was colonized by animals migrating from the denser surrounding populations. On recently restored sites numbers at the boundary were found to be higher than at the site centre. However, on older sites although there was a gradient in biomass and numbers at the edge, the populations at the centre were not significantly different.

Thus either migration is very rapid, so that no edge effect is detectable, or it is not contributing significantly to population increase at either the site centre or boundary. Van Rhee (1969) found A.caliginosa populations spread at 6 m yr^{-2} and A.chlorotica populations spread at 4 m yr^{-2}, suggesting that migration is too slow for the former explanation.

Thus it seems that there was no evidence that earthworms migrate into the sites from the surrounding areas in significant numbers. This conclusion is reinforced by comparison of the changes in population with time at the site edge and centre. The rates of increase and population levels were similar in both areas, suggesting that the same factors are influencing population growth in both areas. This appears to be simply the rate of reproduction of the earthworms already present on the site, without any colonisation.

The gradient at the boundary may initialy be caused by edge effects, the stored soil being mixed with soil from the surrounding area which contains more earthworms, or very slow migration. Such a gradient would then be maintained by reproduction of the earthworms present.

Thus the earthworm population on restored opencast mine sites appears to build up evenly over the whole site. This suggests that the development of the site fauna is entirely dependent on the number of earthworms surviving stripping and respreading. As the initial population is extremely small, and growth is exponential initial recovery is slow, but subsequently gains momentum as the population develops. Thus a small increase in the earthworm population of a newly restored site would have a great effect on the population at the end of the aftercare period. Increasing the founder population to just 5 m^{-2} could increase the number after five years from 32 m^{-2} to 320 m^{-2}.

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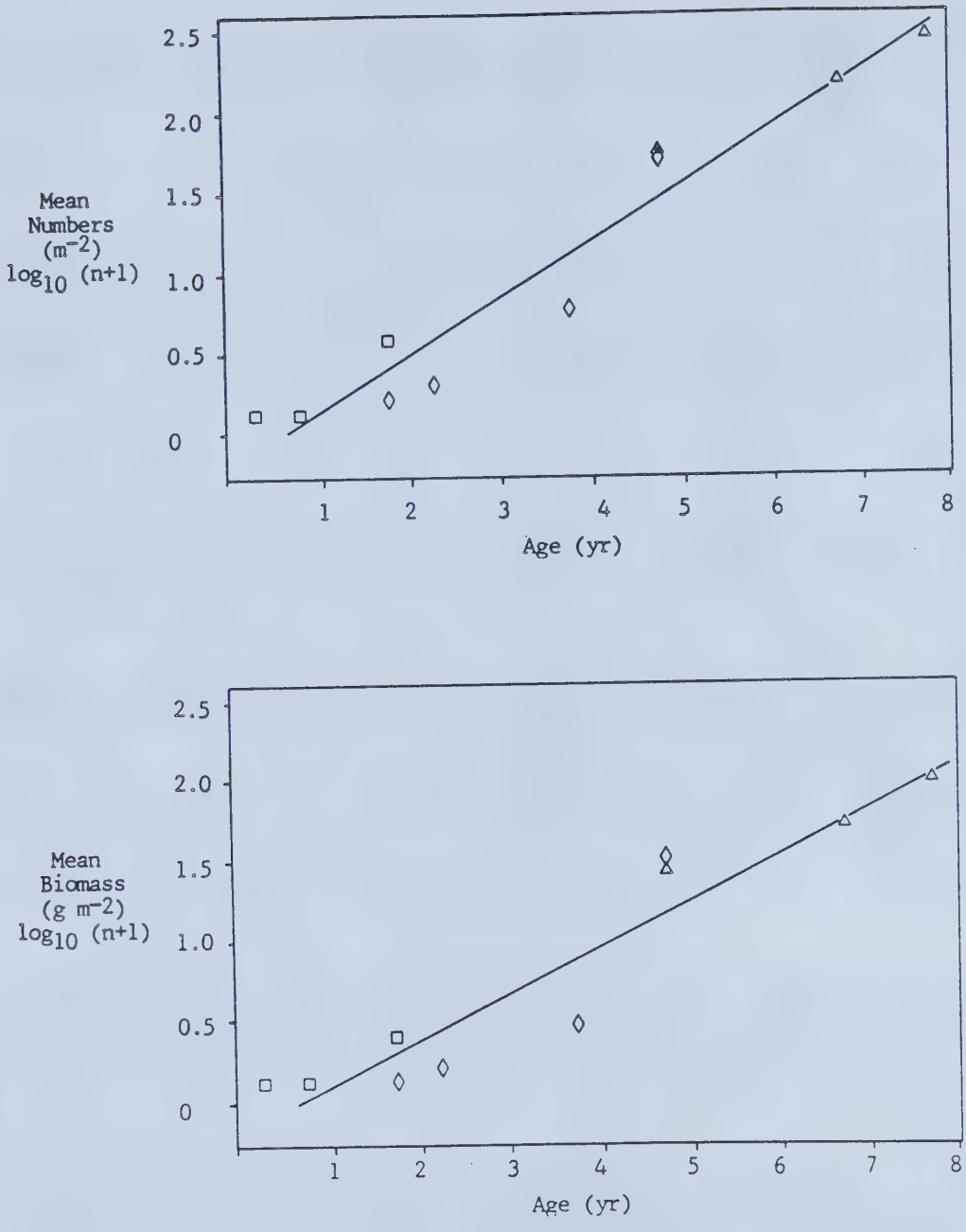

Figure 1: Mean number and biomass of earthworms from site centres and relationship with age

TABLE 1 Mean number, weight and species numbers ($\log_{10}$ (n+1) m^{-2}) of earthworms together with their standard errors (SE) from the centre of sites of increasing age

Age	Number		Weight		A. caliginosa		A. chlorotica		A. longa		L. rubellus		L. terrestris		Number of Species
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	
0.25	0.09	0.04	0.04	0.01	-	-	0.01	0.01	0.02	0.02	-	-	-	-	2
0.75	0.12	0.05	0.09	0.04	-	-	-	-	-	-	-	-	-	-	1
1.75	0.50	0.06	0.38	0.06	0.03	0.02	0.05	0.03	-	-	0.27	0.06	0.04	0.02	6
1.75	0.18	0.06	0.11	0.05	0.09	0.05	-	-	0.05	0.03	-	-	-	-	2
2.25	0.27	0.08	0.20	0.06	0.02	0.06	-	-	-	-	-	-	-	-	4
3.75	0.72	0.10	0.43	0.08	0.39	0.08	0.13	0.06	0.03	0.03	0.16	0.07	-	-	6
4.75	1.70	0.06	1.46	0.07	1.17	0.08	0.80	0.10	0.18	0.07	1.02	0.08	0.02	0.02	8
4.75	1.71	0.05	1.39	0.05	0.93	0.09	1.09	0.12	0.90	0.08	0.48	0.09	0.02	0.02	10
5.25	2.41	0.03	1.75	0.04	1.79	0.05	2.16	0.03	1.25	0.06	0.46	0.08	0.05	0.03	9
6.75	2.13	0.04	1.67	0.05	1.45	0.05	1.75	0.06	1.29	0.05	0.35	0.06	0.02	0.02	11
7.75	2.39	0.05	1.92	0.03	1.67	0.05	2.07	0.07	1.51	0.04	0.24	0.06	-	-	8

TABLE 2 Mean number, weight and species numbers ($\log_{10}$ (n+1) m^{-2}) of earthworms, together with their standard errors (SE) from the boundaries of sites of increasing age

Age	Number		Weight		A. caliginosa		A. chlorotica		A. longa		L. rubellus		L. terrestris		Number of Species
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	
0.25	0.15	0.08	0.24	0.08	0.05	0.03	0.08	0.06	0.05	0.03	-	-	-	-	4
1.75	0.82	0.09	0.72	0.08	0.07	0.05	0.16	0.07	-	-	0.33	0.08	0.08	0.05	7
1.75	0.40	0.10	0.39	0.09	0.03	0.03	0.22	0.07	-	-	0.15	0.07	0.07	0.04	4
3.75	0.65	0.12	0.59	0.11	0.12	0.06	0.08	0.05	0.08	0.05	0.24	0.09	0.06	0.04	9
4.75	1.23	0.10	1.06	0.08	0.20	0.06	0.28	0.08	0.29	0.10	0.65	0.10	0.16	0.07	8
4.75	1.95	0.06	1.50	0.05	1.12	0.09	1.54	0.07	1.05	0.05	0.36	0.10	-	-	9
5.25	2.29	0.05	1.77	0.05	1.73	0.05	1.99	0.05	1.15	0.08	0.17	0.06	0.02	0.02	11
6.75	1.85	0.07	1.43	0.06	1.15	0.07	1.43	0.07	0.68	0.08	0.38	0.08	0.05	0.03	11
7.75	2.32	0.04	1.93	0.05	1.50	0.07	1.95	0.66	1.41	0.04	0.21	0.07	0.09	0.04	9

TABLE 3 : Summary Analysis of Variance of multiple regression of earthworm numbers at site centres and boundaries

	Residual		Change		Mean		
Centre	DF	SS	DF	SS	Change	VR	P
Initial Model	9	7.3357					
Modifications							
+ Age	8	0.4861	1	6.8496	6.849	178.72	<0.001
+ Sites	6	0.3267	2	0.1594	0.080	2.08	ns
+ Age. Sites	4	0.1533	2	0.1734	0.087	2.26	ns
					0.038		

Boundary	DF	SS	DF	SS	Mean Change	VR	P
Initial Model	7	4.423					
Modifications							
+ Age	6	0.664	1	3.759	3.759	56.40	<0.001
+ Sites	4	0.267	2	0.397	0.199	2.98	ns
+ Ages.Sites	2	0.136	2	0.130	0.065	0.98	ns
					0.067		

TABLE 4 Summary Analysis of Variance of multiple regression of earthworm biomass at site centres and boundaries

Centre	DF	SS	DF	SS	Mean Change	VR	P
Initial Model	9	5.016					
Modifications							
+ Ages	8	0.484	1	4.532	4.532	81.53	<0.001
+ Sites	6	0.369	2	0.115	0.058	1.04	ns
+ Ages. Sites	4	0.222	2	0.147	0.0734	1.32	ns
					0.0556		

Boundary	DF	SS	DF	SS	Mean Change	VR	P
Initial Model	7	2.497					
Modifications							
+ Age	6	0.353	1	2.145	2.145	52.29	<0.001
+ Sites	4	0.164	2	0.189	0.094	2.30	ns
+ Age. Sites	2	0.121	2	0.043	0.022	0.53	ns
					0.041		

TABLE 5 : Analysis of Variance of weight and number of earthworms along transects on sites of increasing age

Weight

	DF	MS	VR	P
Age	5	3.1110	131.822	< 0.001
Distance	6	0.1473	2.337	ns
Linear	1	0.6382	27.042	< 0.001
Quadratic	1	0.0145	0.614	ns
Deviations	4	0.0577	2.446	ns
Age. Distance	24	0.0379	1.606	ns
Distance. Linear	5	0.0630	2.671	ns
Distance. Quadratic	5	0.0527	2.235	ns
Deviations	14	0.0236		

Number

	DF	MS	VR	P
Age	5	4.2260	102.573	< 0.001
Distance	6	0.1392	3.379	< 0.05
Linear	1	0.6430	15.607	< 0.01
Quadratic	1	0.0044	0.106	ns
Deviations	4	0.0470	1.140	ns
Age. Distance	24	0.0674	1.636	ns
Distance. Linear	5	0.1259	3.056	< 0.05
Distance. Quadratic	5	0.0823	1.996	ns
Deviations	14	0.0412		

WEATHERING AND PROPERTIES OF COAL MINESPOILS IN THE ROCKY MOUNTAIN FOOTHILLS REGION OF ALBERTA*

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ABSTRACT

Seventeen Coal Valley minespoil samples were analyzed. Twelve samples rapidly weather to single grain structure when immersed in water or exposed to freeze-thaw cycles. Three other samples show minor breakdown under such conditions, and two resist weathering. Samples appear to physcially weather through dissolution of cementing agents in combination with stresses due to smectite expansion and release of overburden pressure. Chemical weathering is limited but seems to favour the release of monovalent cations.

When ground to <2mm particle size seven samples have low SAR, EC and pH but ten samples have an SAR around 30, EC of 1-3 mS/cm, and pH of 8-9. These values would decrease over time under the leaching environment of Coal Valley. The materials do not inhibit plant development under favourable growing conditions. Saturated hydraulic conductivity varies greatly, with three samples having values several orders of magnitude less than 1 cm/day. Physical conditions seem to offer greater problems for reclamation than chemical conditions.

INTRODUCTION

Spoils produced by coal mining operations in the Rocky Mountain Foothills region of Alberta present a number of difficulties when attemptimg to restore the area to a natural self-sustaining ecosystem. The spoils consist of sedimentary rocks of variable grain size, have poor water holding capacity and nutrient status, may form impermeable or unstable zones, and may contain toxic concentrations of salt or sodium. Perhaps the biggest reclamation problem is the uncertainty about how the materials will weather and what the resultant soil properties will be. Therefore, the present study was initiated to examine the weathering and properties of spoil materials from the Coal Valley Mine, operated by Luscar Ltd., in west-central Alberta.

MATERIALS AND METHODS

Coal Valley is located in a boreal forest comprised mainly of young lodgepole pine (Pinus contorta) some 60 km SSW of Edson, Alberta. Steep parallel ridges alternate with gently sloping valleys, giving the region an elevation of 1370 to 1470 m above sea level. Soils are

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

mostly acidic Gray Luvisols, often with Brunisolic or Podzolic influences, indicating a leaching environment, and soil depth varies from several centimetres on the ridges to several metres in the valleys (Knapik and Burton, 1980). Annual precipitation is approximately 70 cm and has a summer maximum. Temperatures are cool and frost can be expected in every month except July.

Laboratory analyses were conducted on seventeen samples from Coal Valley. These samples were assigned laboratory numbers 9 to 26. Since samples 14 and 15 were identical only the results for sample 14 are presented. A description of all samples and their location within the mine is presented in Table 1.

For most physical and chemical analyses samples were first ground to pass a 2 mm sieve to approximate their particle size after physical weathering. This assumes that the materials weather along weak zones formed by the cementing agents both naturally and by grinding. Hydraulic conductivity was measured in soil permeability cells[1] using four replicates for each sample. Particle size was determined by pipette (McKeague, 1978). Cation exchange capacity was determined by sodium acetate; soluble cations, sodium absorption ratio (SAR), pH and electrical conductivity (EC) were measured on saturation paste extracts (McKeague, 1978) using standard atomic absorption and emission techniques for cations. Calcium carbonate equivalent was determined by the method of Allison and Moodie (1965). X-ray diffraction (XRD) was used for clay mineral analysis on four heavy-textured samples. Soil dispersion was evaluated by suspending 5 g spoil in 100 ml solutions of varying concentration but with similar ionic composition as the saturation paste extracts from the sodic spoils and recording if flocculation occurred.

Plants were grown in each of the spoil materials to determine whether plant development was retarded in any medium. Ten oat and 50 alfalfa seeds were planted in each pot and monitored for germination and plant development under both unfertilized and fertilized (20-20-20) conditions. To determine which nutrients were lacking in the spoils fertilizer trials were conducted in 10 cm pots using sample 11 as the growth medium. Eight fertilizer combinations were selected including nothing (control), N, P, K, NP, NK and NPK, using two replicates per treatment and 0.20 g of each specified nutrient element per pot. Dry matter was determined after 38 days as flower buds were appearing.

Weathering in distilled water was performed by placing rock samples in water and monitoring physical breakdown over 31 days. Samples were subjected to 41 freeze-thaw cycles to evaluate the effects of frost shattering. Weathering of ground samples by 68 days shaking in distilled water and by soxhlet apparatus (Singleton and Lavkulich, 1978) were used to determine long-term chemical weathering.

[1] A modified design of the tempe cell, currently being patented by the Soils Group, Alberta Environmental Centre.

Soxhlet leaching rates were limited by the hydraulic conductivity of the samples such that only the most porous samples (18, 19, 20, 22 and 24) could be used. None of these samples had salt or sodicity problems. Over a one month period samples had an amount of water passed through them corresponding to a vertical column between 7.2 and 75 m in depth, depending on the sample. Soxhlet liquors were analyzed after every 15 m leaching, with the final leaching not necessarily corresponding to 15 m. Ammonium acetate extractions were done on fresh samples and on leached samples using 1:20 soil to solution ratios.

The prolonged shaking experiment used 50.00 g of each sample in 200 ml distilled water. At intervals of 1 day, 1 day, 2 days, 4 days, 4 days, 28 days and 28 days the samples were centrifuged, the leachate was analyzed and fresh water was added. The amount of water remaining in each sample after each extraction was determined gravimetrically and the effects of carrying some liquid from one extraction to the next was then removed from the results. Ammonium acetate extractions were done on fresh samples and on leached samples.

RESULTS AND DISCUSSION

Some of the laboratory results are presented in Table 2. An EC>4mS/cm or an SAR>8 has deleterious effects on plant development (Richards, 1954) such that all of the samples have acceptable EC but 10 have excessive SAR, indicating that Na may interfere with the adsorption of other cations. Most of these samples contain appreciable amounts of Ca (as calcium carbonate) which could replace Na if the latter were leached. pH in most of the samples is rather high due to both the Na and carbonate content. Texture and CEC show considerable variation.

Semi-quantitative clay mineral analysis was performed on clay fractions from samples 14, 19, 21 and 26, representing one clay-rich sample from each of the mine zones. Sample 14 proved to be 100% smectite which explains why this sample undergoes severe swelling upon wetting. The other samples are a mixture of kaolinite (5-40%), smectite (25-35%), illite (20-45%), chlorite (5-20%), with traces of quartz and plagioclase. These samples exhibit less swelling due to the smaller amounts of smectitic clays.

The saturation paste data indicates that the ten samples with high SAR have variable total salt concentration but very similar ionic composition which on a me/l basis is 95% Na, 2% Ca, 2% Mg and 1% K, with chloride as the major anion. A similar stock solution was prepared and was used for the dispersion experiments and one phase of the hydraulic conductivity experiments. In this solution most samples, especially those high in Na, did not form flocs greater than 2 um until solution salt concentrations reached 20-30 me/l. The soluble salt data of Table 2 shows that saturation extracts from the spoil samples have salt concentrations of 10-30 me/l. Moisture in saturation pastes is about double field capacity moisture and quadruple wilting point moisture (Richards, 1954), such that samples in the field would vary from about 20-120 me/l salt concentration.

Therefore, only at the upper end of field moisture regimes would these samples begin to disperse, although rapid leaching of salts by rainfall or artificial means could cause dispersion and crusting in the upper layers of spoil.

Richards (1954) states that samples with hydraulic conductivity less than 6 cm per day have special water management problems. Using this criteria samples 9, 14, 17, 23 and 25 present problems in distilled water. These samples were retested using a 20 me/l salt solution (approximating saturated flow salt concentration) which resulted in approximately a tenfold increase in hydraulic conductivity, but samples 9, 14, 23 and 25 still had values of less than 6 cm/day.

Samples 9 (3.42×10^{-2} cm/day), 14 (2.27×10^{-4} cm/day) and 23 (1.02×10^{-3} cm/day) have such poor hydraulic conductivity that they present serious problems. This might be alleviated by mixing these samples with the most porous materials from the same mine zone. For samples 9 and 14 from the Mynheer A zone sample 12 (42.3 cm/day) is the best candidate; for sample 23 from the Val D'or zone sample 22 (220 cm/day) offers the greatest hydraulic conductivity. Spoils are a mixture of boulders of varying size which would be extremely difficult to model in the laboratory so homogenized mixes of samples were used under the assumption that eventually the boulders would weather and clays would disperse throughout the mixture.

Figure 1 illustrates the hydraulic conductivity results for the various mixes. Using the 6 cm/day criteria, interpolation shows that this limit is reached at about 14% sample 9, 10% sample 14 and 27% sample 23. Greater concentration of these samples may result in unacceptably low hydraulic conductivity over time, although soluble salts and the development of soil structure may permit somewhat higher mixing ratios. In growth trials these samples developed cracks which greatly improved infiltration and this may also occur in surface soils in the field.

A logarithmic relationship does not precisely define the hydraulic conductivity results but it does provide a good approximation. Actual values are slightly less than predicted by a logarithmic relationship. Based on the results an equation can be developed for predicting the results of other mixes:

$$\text{conductivity mixture} = 10^{(x \log A + y \log B)}$$

where A and B are the two samples; x and y are the portion of the mixture occupied by samples A and B respectively.

It seems reasonable that this equation could be extended for mixes of 3 or more samples by adding additional terms to the exponent.

Germination, especially of alfalfa, appeared to be retarded in the spoil materials when compared to control pots of potting soil, but no statistically significant differences were found. In fertilized pots plant growth and development was excellent in all materials at all

phases of the experiment. In unfertilized pots plant development was similar in all pots, although growth was somewhat lusher in the more fertile control samples. The spoil materials appear to offer some resistance to emergence of weak seedlings such as alfalfa but no problems for plant development apart from low fertility. However, this conclusion was reached under almost ideal growing conditions; a more stressful environment might produce different results.

Total extractable cations (soluble, exchangeable, and poorly soluble) based on 1:20 extracts of soil:ammonium acetate solution were compared before and after the growth experiments with the before-after differences grouped and analyzed for statistical significance. Only Mg showed a significant increase after the growth trials, amounting to 0.3 me/100 g, but no other weathering experiment indicated any significant release of Mg. If removal of nutrients by plants is taken into account K release was also significant.

The results of the dry matter yields from fertilizer trials are illustrated in Figure 2. Using Duncan's Multiple Range test at a 5% and 1% significance level the NP and NPK treatments are significantly different from all other treatments at a 1% level and no other treatments show any significant difference. Given that the experiment used only 2 replicates so has limited resolution the effect of the NP combination is dramatic. While only sample 11 was tested this situation likely holds true for all samples; in some very sandy materials K might also be limiting.

Since many samples appear to be cemented with Ca carbonate which should solubilize or soften in water and since smectite is present in all samples tested and would produce stresses upon swelling in water, all samples were tested for breakdown in distilled water. Six samples had a soil-like consistence and were readily softened in water, as were three sandstones. Of the remaining eight samples, 11, 13 and 26 were fractured to pieces less than 1 cm in diameter in water, and frost action reduced these to single grains in a separate experiment. Samples 19, 21 and 22 underwent partial breakdown in water, with sample 21 showing a minor additional effect by frost. Sample 14 showed no evidence of breakdown in water but a slight effect due to frost; since this sample has very poor hydraulic conductivity when weathered its resistance may prove beneficial. Sample 10 showed no evidence of weathering by water or frost and is currently used for roadbed construction.

The limited action of frost as a weathering agent for most samples is due to the remarkably effective breakdown that occurs in water. Since frost-treated samples were kept saturated the freeze-thaw experiment contains both a wetting and a frost component. Frost can only appear as a complementary action to wetting and since wetting is so effective at weathering most samples any effect by frost is inconsequential.

Of the approaches outlined by Clayton (1979) to evaluate long-term chemical weathering only laboratory methods can be considered appropriate for this study due to time and resource constraints. Two

techniques were selected: a modified soxhlet extraction apparatus (Singleton and Lavkulich, 1978) which stimulates hydrolysis and leaching reactions, and extended end-over-end shaking (68 days) in distilled water.

The soxhlet data was examined for before leaching - after leaching extractable cation differences (before = ammonium acetate extractable prior to leaching; after = extractable after leaching + cations leached by soxhlet extractor) to determine if Ca, Mg, Na or K had been released by weathering. The data was tested for statistical significance using a paired t-test to examine the before-after differences for each cation. The six samples were grouped together as non-sodic Coal Valley spoils. No significant release of Ca or Mg was indicated, but K weathering was significant at a 5% confidence level and Na at a 1% level. Because an unidentified insoluble precipitate formed in all soxhlet flasks and only a limited number of samples could be tested this test would seem to require modification to be practical for a study such as this.

Results from the extended shaking in water were analyzed as for the soxhlet extractions. For each element the 17 samples were grouped together for statistical analysis. However, Na concentrations show two distinct ranges so Na was also analyzed by grouping the 10 Na-rich samples and the 7 Na-poor samples. As with the soxhlet data there was no significant release of Ca or Mg, but K weathering was significant at the 1% level. Na weathering was not significant for the group of 17 samples or for the Na-rich samples, but was significant at the 1% level for the Na-poor samples even though the mean release for this group was less than for the Na-rich samples.

Hardy Associates (1981) determined the oxide content of six Coal Valley rock samples and found 1-13% Ca and Mg oxides and <0.1% Na and K oxides. Since the former oxides are more easily weatherable (Anderson and Hawkes 1958; Loughnan, 1969) it is suprising that the Coal Valley samples seem to release more Na and K. Most likely the Ca and Mg oxides are in the form of carbonates which were extracted both before and after leaching by ammonium acetate so do not show up as weathered minerals by the techniques used here. In any case, the total Na and K content appears small so increased salinity problems due to weathering are unlikely.

SUMMARY AND CONCLUSION

When exposed to moisture and freeze thaw conditions most of the samples tested showed complete or considerable physical weathering. Chemical weathering was limited as these materials are sedimentary so have undergone previous chemical weathering which removed many weatherable minerals.

The high SAR, EC, and pH of many samples does not appear to affect plant development. It seems that physical problems such as poor water retention in sandy materials, dispersion and crusting, and extremely poor hydraulic conductivity in smectitic materials pose much greater

reclamation difficulties than chemical properties.

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Table 1. Coal Valley minespoil descriptions.

Sample	Mine Zone	Description
9	Mynheer A	Sandstone spoil
10	Val D'or	Sandstone
11	Mynheer A	Mudstone
12	Mynheer A	Sandstone
13	Mynheer A	Siltstone
14	Mynheer A	Silt/mudstone, smectitic
15	Mynheer A	Silt/mudstone, smectitic
16	Mynheer A	Pre-1960 spoil
17	Mynheer A	Recently levelled spoil
18	Mynheer B	Sandstone
19	Mynheer B	Recently levelled spoil
20	Mynheer B	Pre-1960 spoil
21	Val D'or	Siltstone
22	Val D'or	Sandstone
23	Val D'or	Recently levelled spoil
24	Silkstone	Recently levelled spoil
25	Silkstone	Sandstone
26	Silkstone	Silt/mudstone

Table 2. Properties of Coal Valley minespoils.

Sample	pH[1]	E.C.[1] mS/cm	Soluble[1] Cations (me/l)	SAR[1]	Texture[2]	C.E.C. me/100 g	% $CaCO_3$ equivalent
9	8.92	1.41	15.3	25	L	37.2	2.9
10	8.82	2.75	29.2	36	SL	7.5	17.1
11	8.87	1.62	16.9	37	CL	31.6	0.6
12	8.70	1.61	16.2	28	SL	12.0	14.0
13	8.89	2.02	20.5	45	L	33.7	1.6
14	8.90	0.96	9.7	24	CL	59.8	3.4
16	7.72	0.31	3.3	0	L	33.1	0.4
17	8.10	0.91	8.3	12	CL	41.6	1.7
18	7.52	0.48	4.4	0	SL	16.4	6.7
19	7.78	0.26	2.5	0	SL	19.1	2.7
20	6.67	0.13	0.7	0	SCL	33.2	0.0
21	8.23	1.35	12.5	32	CL	29.4	0.7
22	7.83	0.47	4.5	2	SL	7.9	5.0
23	8.40	1.09	10.3	30	CL	31.2	3.3
24	7.92	0.37	3.4	2	SCL	30.7	1.4
25	8.37	0.82	8.0	29	SL	3.1	3.0
26	7.88	0.52	5.2	0	SL	25.5	4.2

[1] Determined on saturation paste extracts

[2] L - loam, S = sandy, C = clay

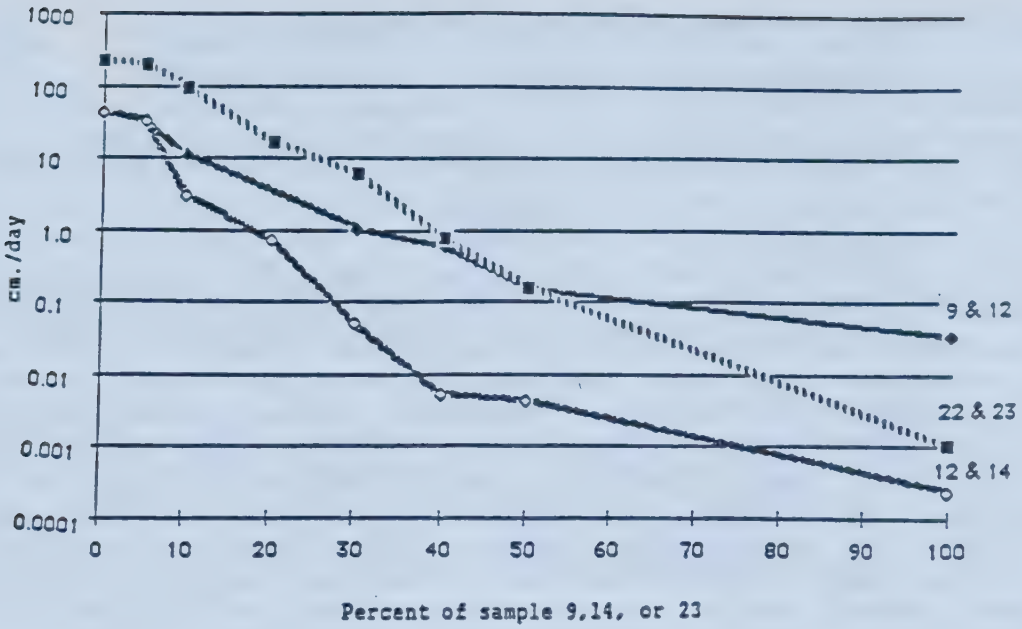

Figure 1. Saturated hydraulic conductivity of mixed samples.

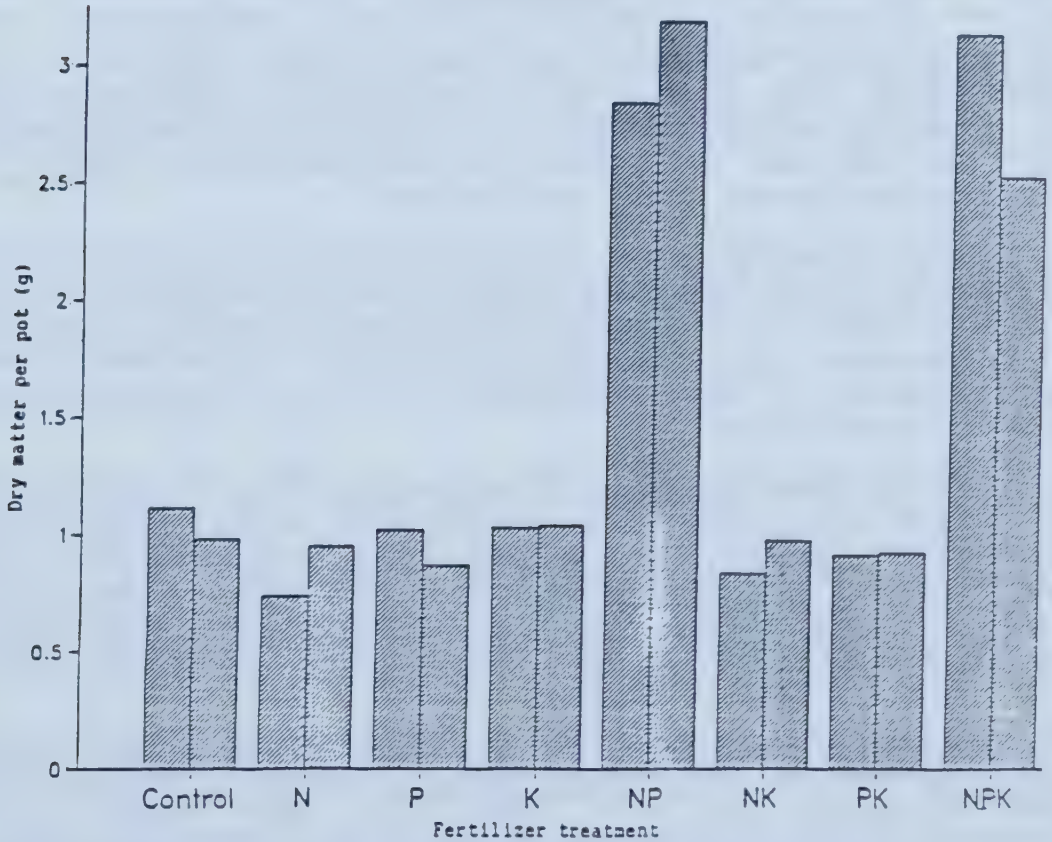

Figure 2. Dry matter yield per pot in fertilizer trials.

BACTERICIDES: A MODERN APPROACH TO RECLAMATION*

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ABSTRACT

Bactericides, in the form of anionic detergents, have been shown to inhibit the bacteria T. ferrooxidans which otherwise catalyze the formation of acid mine drainage from pyritic material. Liquid sprays are effective for short periods of time and are useful for initial rapid inhibition of bacteria. Controlled release pellets provide the required concentration of bactericide over prolonged periods of time sufficient to permit healthy growth of vegetation on the reclaimed material. Both sprays and pellets were utilized in the reclamation of sites in Ohio and West Virginia. The effects of the bactericide treatments were studied for more than two and one-half years. Microbiological and soil moisture examinations were done periodically to establish patterns and cycles. Tests showed inhibition of T. ferrooxidans, proliferation of heterotrophs, decrease in acidity, iron, aluminum and manganese and development of strong, healthy, self-regenerating vegetation on both sites.

INTRODUCTION

Pyritic materials associated with coal refuse oxidize and form mineral acids when exposed to the atmosphere. Acid mine drainage (AMD) from the refuse degrades surface water quality and the aquatic environment and may contaminate the local groundwater system. The refuse material becomes acidic and biotoxic.

The acidic refuse material erodes easily and contaminates adjacent lands. This cycle continues because erosion exposes unweathered pyritic material for oxidation. This oxidation process is catalyzed by the bacteria Thiobacillus ferrooxidans. A pH dependent three-stage mechanism of acid generation has been proposed (Kleinmann, Crerar and Pacelli, 1981).

Inhibiting or destroying these bacteria can significantly slow the rate of acid production. Anionic surfactants, organic acids and food preservatives (Onysko et al., 1984) act as bactericides and destroy these bacteria; however, bactericides degrade with time and are lost because of leaching and run-off. To overcome this inherent short duration effectiveness of spray applications, controlled release systems were developed (Sobek et al, 1985).

Control of acid generation for prolonged periods greatly enhances reclamation efforts and can reduce reclamation costs by reducing the

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Assoc., Laurentian University, Sudbury, Ontario, June 7-11, 1987.

amount of topsoil needed to establish vegetation (Rastogi and Sobek, 1986). A strong vegetative cover for three years or more can break the acid production cycle due to three natural biological processes: (1) a healthy root system competes for both oxygen and moisture with acid-producing bacteria; (2) populations of beneficial heterotrophic soil bacteria and fungi are reestablished, resulting in the formation of organic acids which are inhibitory to T. ferrooxidans (Tuttle et al, 1977); (3) the action of plant root respiration and these heterotrophic bacteria increase CO_2 levels in the spoil resulting in an unfavorable microenvironment for growth of T. ferrooxidans.

The objectives of this paper are to demonstrate that a modern bactericide system consisting of a combination of liquid spray and controlled release pellets will effectively reduce acid formation, will continue to suppress the generation of additional acid and will provide an environment for the proliferation of heterotrophic microorganisms which promote self-regenerating healthy vegetation after reclamation.

BACKGROUND

Sites Studied

Two abandoned refuse areas were studied before and after reclamtion with bactericides. The first site, called the Route 43 site (Figure 1) is located in southeast Ohio. It covers approximately 5-6 acres and is roughly triangular in shape. The site is situated on a hillside which drops about 85 feet from the top of the hill to a rain-fed stream flowing across the base of the hill from southeast to northwest.

The second site, called the Norton site (Figure 2), is located near Norton, West Virginia. It covers about 25 acres of rolling country from 1940 feet to 2060 feet elevation. A stream runs generally south to north along the eastern edge of the site.

Site Treatments

The triangular shape of the Route 43 site was divided into two approximately equal parts as shown in Figure 1. The northern (left) half was treated with bactericides consisting of a combination of liquid spray and controlled release pellets after grading and contouring of both sides. Following bactericide treatment, both sides were covered with 6-8 inches of topsoil followed by fertilizer, lime, seed and hay mulch.

The Norton site was graded to final contours before the bactericide treatment was applied. A one-acre area was left untreated for use as a control area. The entire site, both treated and untreated areas, was then covered with about 6 inches of topsoil material and received customary lime, fertilizer, seed and hay mulch.

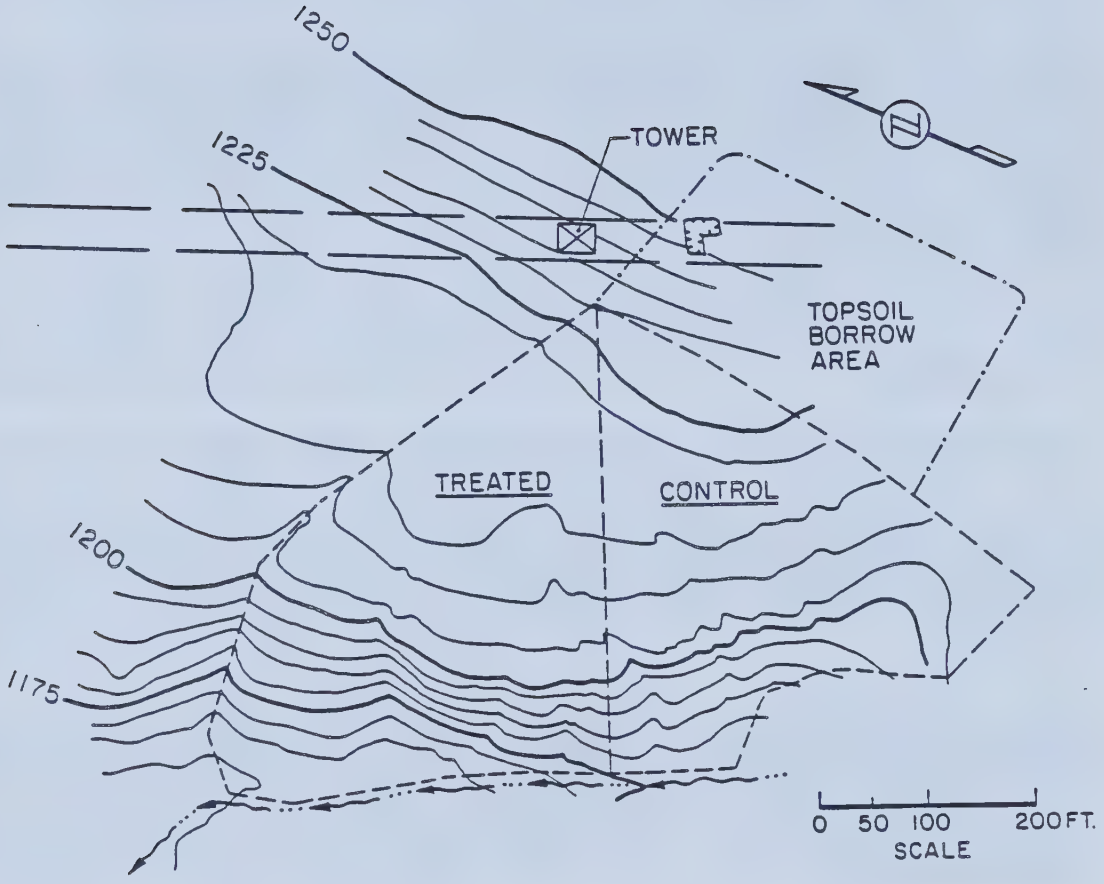


Figure 1. Route 43 Site, Southeast Ohio

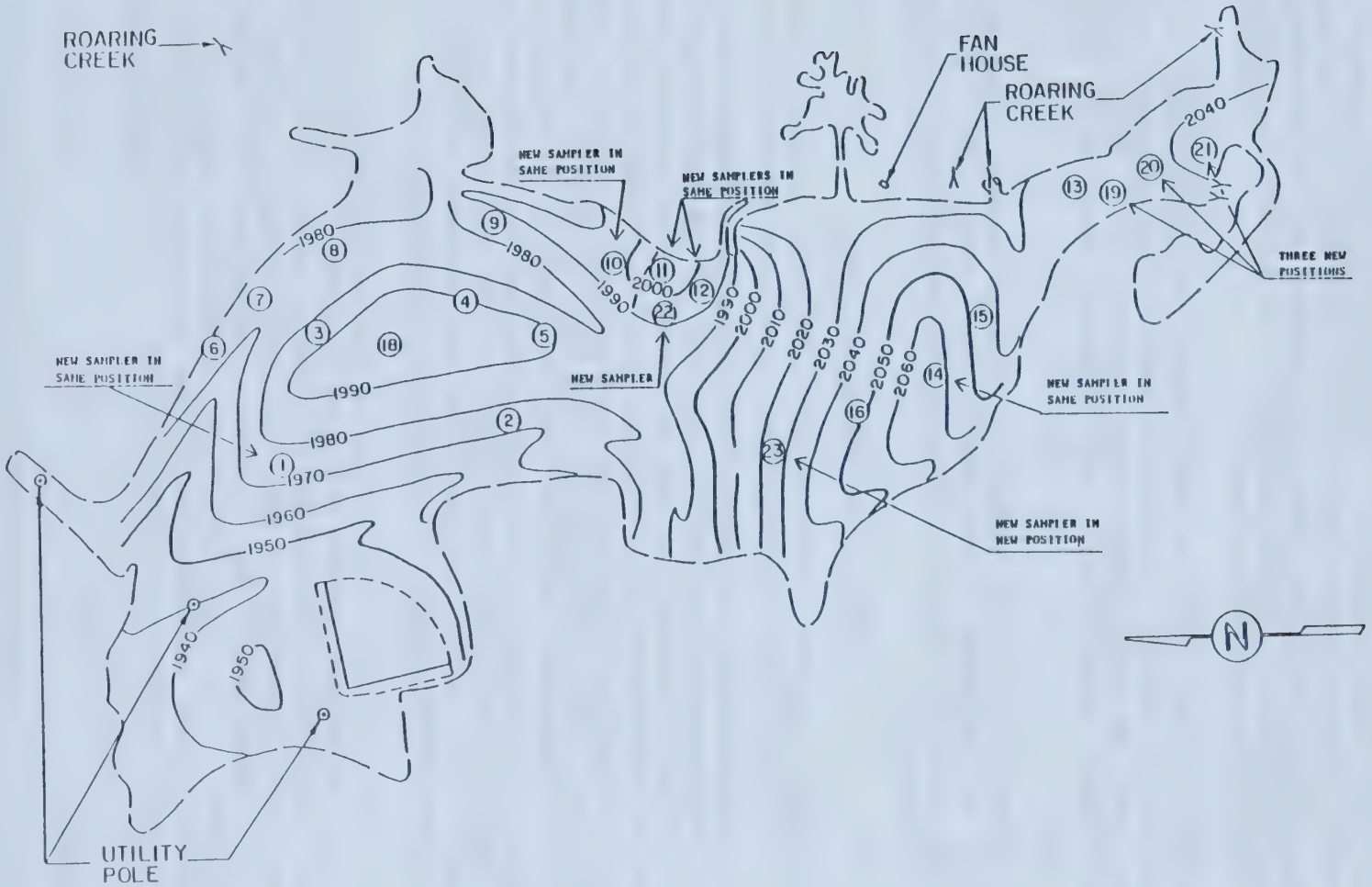


Figure 2. Norton, West Virginia Site

Site Monitoring

Eight soil moisture samplers (pressure-vacuum lysimeters) (Figure 4) were installed at different locations on the Route 43 site. It was expected that the effects of the bactericide application would be noticeable first in the vadose zone, and then in the rain-fed stream. Actual response times are controlled by the weather and refuse pile porosity. Other instruments installed on the site were a rain gauge and an evaporation pan.

Monitoring of the site included periodic water collection and site inspections of surface vegetation cover and acid generation during the two and one-half years after reclamation. Other parameters monitored were precipitation and bacterial activity in the refuse pile.

Twenty three soil moisture samplers (pressure-vacuum lysimeters) were installed at different locations on the Norton site and it was monitored similarly, including chemical characteristics of refuse and bacterial activity.

DISCUSSION OF ROUTE 43 SITE

Refuse Moisture Data

The data summarized in Tables 1 and 2 are the average of all water quality measurements from samples taken out of the four lysimeters in the bactericide treated portion of the site and compared with the average of all water quality measurements from samples taken out of the four lysimeters in the untreated portion of the site for year one and year two after reclamation. The data in Table 1 indicates the bactericide treatment has been very successful in reducing all parameters in solution, especially aluminum and manganese for the first year. In the second year (Table 2), the reductions continue to be large. Both sets of data show bactericides are effective in reducing acid generation by eliminating T. ferrooxidans.

Figures 3 and 4 show the lysimeter data graphically on a monthly basis for thirty-two months following reclamation. The differences in the individual parameters (acidity, total iron, sulfates, manganese, and aluminum) when the treated area is compared to the control (untreated) area are indicative of bactericide effectiveness. The treated area parameters continue to show consistently lower concentrations than the same parameters in the control area, showing the effectiveness of the controlled release pellets.

Microbiology

A study of the growth of heterotrophic microorganisms in the bactericide-treated area versus the untreated area was made. This

Table 1. Lysimeter Data* Showing Differences in Measurements between Treated and Untreated Areas for the First Year after Reclamation

Parameter	Treated Area	Untreated Area	Percent Reduction in Treated Area
Acidity (mg/L $CaCO_3$)	1003	3563	72%
Specific Conductance (umhos/cm)	2492	3806	35%
Total Iron (mg/L)	236	490	52%
Aluminum (mg/L)	15.3	273.1	94%
Manganese (mg/L)	2.9	43.9	93%
Sulfate (mg/L)	1603	5088	68%

*Data was the average of all measurements from all lysimeters in the treated and the untreated areas for the entire year

Table 2. Lysimeter Data* Showing Differences between Treated and Untreated Areas for the Second Year after Reclamation

Parameter	Treated Area	Untreated Area	Percent Reduction in Treated Area
Acidity (mg/L $CaCO_3$)	1489	3564	58%
Specific Conductance (umhos/cm)	2627	3857	32%
Total Iron (mg/L)	375.9	1392	73%
Aluminum (mg/L)	54.1	600.6	91%
Manganese (mg/L)	7.9	74.5	89%
Sulfate (mg/L)	1975	4672	58%

*Data was the average of all measurements from all lysimeters in the treated and the untreated areas for the entire year.

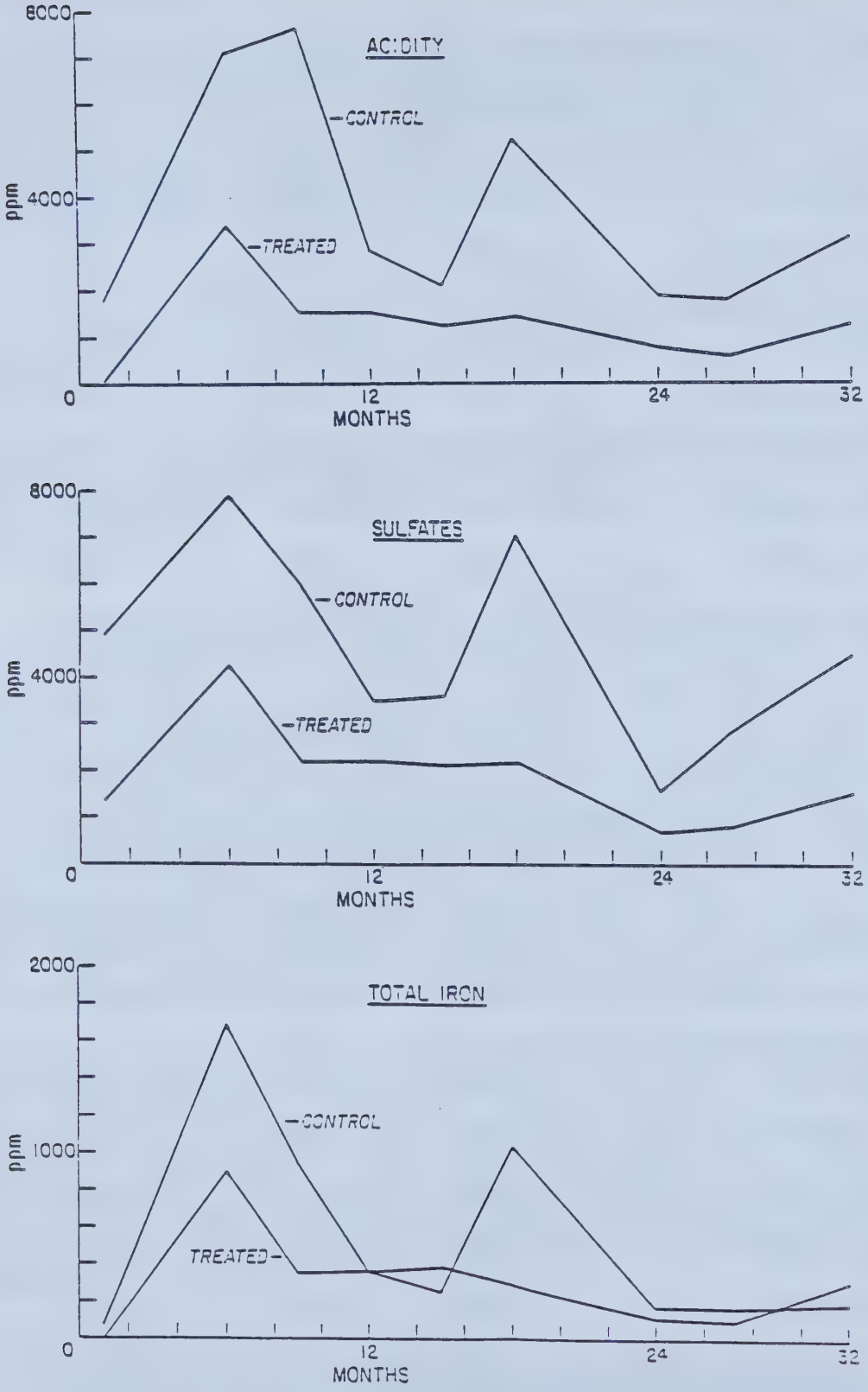
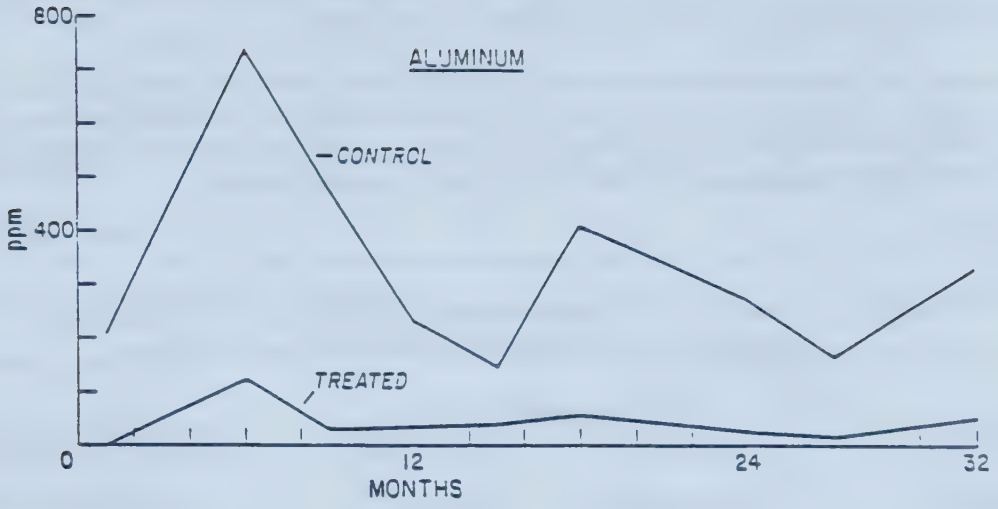


Figure 3. Data from Route 43 Site



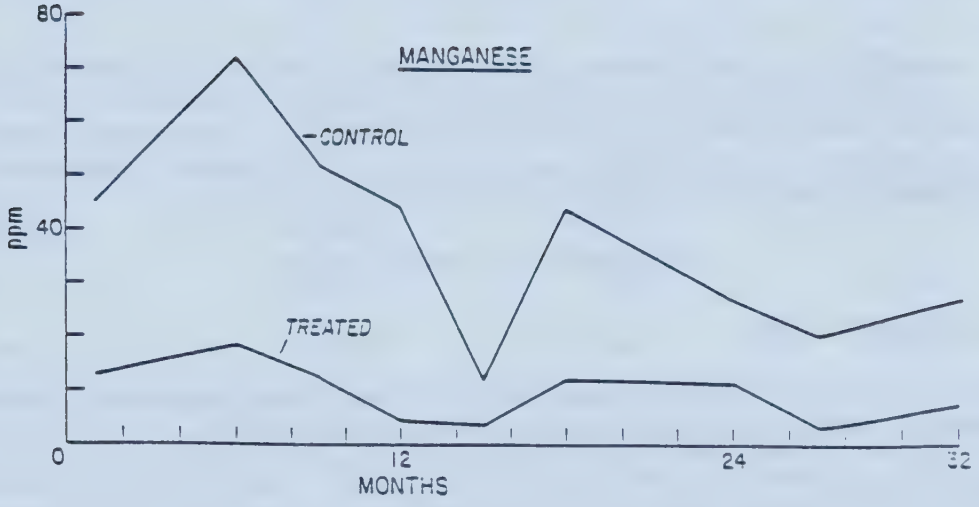


Figure 4. Data from Route 43 Site

comparison was conducted for composite samples of the topsoil and for composite samples at the soil-refuse interface.

The results of the heterotroph growth study (Table 3) indicate that the treated area clearly has more heterotrophic microorganisms than the untreated area. The soil-refuse data indicate a strong trend toward heterotrophic development in the treated area.

Table 3. Ratio of Heterotrophic Bacteria in Composited Samples from Treated and Untreated Areas

Samples	Heterotrophs (MPN/g)		Ratio
	Treated	Untreated	Treated/Untreated
Topsoil	16,582,000	384,326	43:1
Soil-Refuse	457,846	6,714	68:1
Combined	17,039,846	391,040	44:1

The treated area has a denser vegetative cover and is producing much less acidity than the untreated area, although both have approximately the same amount of cover soil. The treated area has much volunteer legume growth as a result of nitrogen fixation by the higher heterotroph population.

DISCUSSION OF NORTON SITE

Refuse Moisture Data

The data in Table 4 are a composite of data from lysimeters placed in the treated and control areas on this site (Figure 6).

Refuse

Paste pH of refuse in the treated area averaged 6.0 compared to 4.4 in the control area.

Microbiology

Average MPN values for T. ferrooxidans in the soil and refuse for the treated and control areas are shown in Table 5. The control area has a far greater T. ferrooxidans population.

Table 4. Composite Water Quality from Lysimeters

Parameters	Change Since Reclamation (21 Months) Treated Area	Control Area
Acidity (mg/L $CaCO_3$)	+31%	+219%
Specific Conductance (umhos/cm)	-72%	- 56%
Iron (mg/L)	below detectible levels	
Aluminum (mg/L)	-76%	+ 50%
Manganese (mg/L)	-95%	- 86%
Sulfates (mg/L)	-77%	- 39%
pH	-11%	- 12%

Table 5. Average MPN Values of T. ferrooxidans Population Density for Soil and Refuse

Samples	T. ferrooxidans (MPN/g) Treated	Control	Ratio (Treated/Control
Soil	0.13	28	1:215
Refuse	4.80	1925	1:401

Ratio analysis of T. ferrooxidans data from composite soil samples (Table 5) indicates that over 400 times as many T. ferrooxidans remained in the refuse in the control or untreated area compared to the treated area. This prolonged low population density of T. ferrooxidans in the treated area is evidence of the effectiveness of the controlled release bactericide treatment.

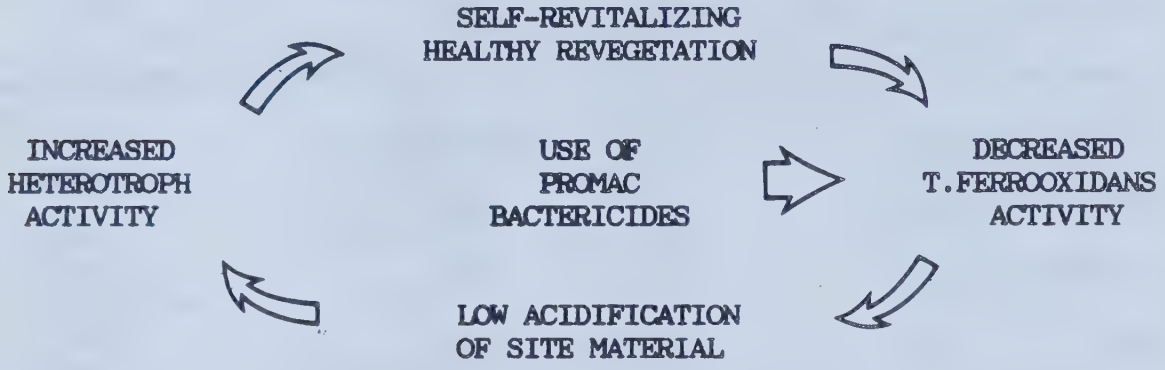
SUMMARY

The following conclusions were developed from the Route 43 and Norton site studies.

A. Soil moisture data from both sites showed significant decreases in acidity, sulfates, manganese, iron and aluminum following bactericide treatment. These decreases were the direct result

of the inhibition of T. ferrooxidans activity which reduces the generation of acid and the subsequent solubilization of metals.

B. Soil moisture measurements for more than two and a half years following bactericide treatments show that heterotrophic microorganism populations have proliferated. These population increases promote stable luxuriant vegetation and establish the following biological cycle which assures self-generating healthy vegetation.



C. Solid, healthy, self-revitalizing vegetation is evident on the sites and will remain until the site is disturbed again.

ACKNOWLEDGEMENTS

The authors wish to acknowledge with thanks the pioneering efforts of Bob Baker, Ohio Department of Natural Resources, and Pat Park, West Virginia Department of Energy, for cooperating with us in conducting these studies.

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CONTROL OF ACIDIC DRAINAGE FROM WASTE ROCK AND SULFIDE TAILINGS BY CHEMICAL INHIBITION OF IRON-OXIDIZING BACTERIA*

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ABSTRACT

Anionic surfactants, such as sodium lauryl sulfate (SLS), and food preservatives, such as salts of benzoic and sorbic acid, have been shown effective in the control of acid production in coal refuse. Pilot-scale tests of these inhibitors were conducted on highly oxidized sulfide tailings, unoxidized sulfide tailings, and waste rock. In the experiment, two sample sizes were used, 7 kg and 100 kg. The 100-kg samples of each material were treated once with a 600-mg/kg dose of SLS or potassium benzoate. The 7-kg samples were treated with a high (600 mg/kg) or low (60 mg/kg) dose of SLS, potassium benzoate, or potassium sorbate. The treated samples and untreated control samples were subsequently leached once per week with filtered demineralized water (an amount equivalent to 2.54 cm of precipitation). The most successful inhibition was found in treatment of waste rock. For the 100-kg samples of the waste rock, SLS and potassium benzoate completely inhibited iron-oxidizing bacteria repopulation for 26 and 36 weeks, respectively. Acidity in the leachate from the 100-kg samples treated with SLS and benzoate remained below the untreated control for 41 and 49 weeks, respectively. In the 100-kg samples, repopulation of iron-oxidizing bacteria was inhibited by both SLS and potassium benzoate in the fresh sulfide tailings, but no bacterial inhibition was observed in the oxidized sulfide tailings. Neither treatment reduced water quality contaminant levels in the oxidized or unoxidized sulfide tailings.

INTRODUCTION

The U.S. Bureau of Mines is currently researching at-source control of acid mine drainage (AMD). AMD is formed by water and oxygen reacting with the sulfide minerals that are associated with coal and metal mining wastes. A common remedy to AMD is chemical treatment of the contaminated water with alkaline materials such as lime, limestone, sodium hydroxide, or sodium carbonate. These treatments raise pH, reduce acidity, and precipitate metals. Chemical neutralization is expensive, may be necessary for many years, and generates large volumes of sludge.

A more direct approach is to stop or slow the pyrite oxidation process and consequent water contamination. The chemical reactions involved in the formation of AMD are as follows:

*Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

$$2FeS_2 + 7O_2 + 2H_2O = 2Fe^{2+} + 4SO_4^{2-} + 4H^+, \quad (1)$$

$$4Fe^{2+} + O_2 + 4H^+ = 4Fe^{3+} + 2H_2O, \quad (2)$$

$$FeS_2 + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+. \quad (3)$$

The sulfide moiety of pyrite (FeS_2) can be oxidized by oxygen (Eq. 1) resulting in ferrous iron (Fe^{2+}), sulfate (SO_4^{2-}), and acid (H^+). Ferrous iron can then be oxidized to ferric iron (Fe^{3+}), which can directly oxidize pyrite (Eq. 3). This results in additional ferrous iron, sulfate, and acid. The rate-limiting step of FeS_2 oxidation is equation 2, which proceeds slowly in the absence of iron-oxidizing bacteria such as Thiobacillus ferrooxidans (Singer and Stumm, 1970). These bacteria, which are indigenous to areas where pyrite occurs, can accelerate the rate of equation 2 as much as 1×10^6 times (Singer and Stumm, 1970). The catalytic activity of these bacteria may be the cause of over 80 pct of the AMD problem in the United States (Browning, 1970).

Various chemicals can be used to inhibit T. ferrooxidans. Sodium lauryl sulfate (SLS) and other surfactants have been shown to reduce AMD in laboratory-scale, pilot-scale and full-scale field tests on coal refuse (Stancel, 1982, Kleinmann and Erickson, 1982). A disadvantage of applying surfactants in solution form is the necessity to intermittently repeat the application. However, even with their short effective duration and need to reapply every three to six months, anionic surfactants can be more cost effective than treatment of the original highly acidic water. To remedy the need to reapply the surfactant, Kleinmann et al. (1980) developed use of SLS-impregnated rubber pellets that would slowly release SLS over a longer period of time.

In an attempt to identify chemicals that may have a longer effect when added as solutions, organic acids and their ability to form sparingly-soluble salts were studied Onysko et al. (1984a). It was hypothesized that these salts would precipitate on pyrite surfaces and these precipitates would be capable of dissolving to the biologically active form. This scheme was intended to extend the inhibitory effects of these chemicals. Salts of benzoic acid and sorbic acid were deemed appropriate for study Onysko et al. (1984b). In laboratory and pilot-scale tests on coal refuse, benzoate and sorbate were found to be effective bacterial inhibitors, however, no extension of inhibition was noted relative to conventional SLS solution application.

Because similar chemical reactions (Eqs. 1, 2, and 3) take place in metal mine wastes, inhibition of T. ferrooxidans may also reduce acid production from these wastes. The intent of this study of acidic drainage formation in metal mine wastes was to determine: (1) if these chemicals (surfactants and organic acids) would inhibit the iron-

oxidizing bacteria, (2) if inhibition of these bacteria would reduce acid production, and (3) the effectiveness and duration of the chemical treatments at two dosage rates.

WASTE MATERIALS

The waste materials tested were oxidized and unoxidized sulfide tailings, and waste rock. These materials are common wastes resulting from metal (copper, zinc, silver, and gold) mining.

The unoxidized and oxidized sulfide tailings came from a metal mine in Quebec, Canada. The ore from this mine is passed through a concentrator and processed for recovery of copper, zinc, pyrite, gold, and silver. The ore passes through multiple crushers, grinders, and flotation cells. The waste product from the flotation cells constitutes the sulfide tailings (70 pct less than 200 mesh). The oxidized sulfide tailings used in the experiment were taken from the surface of a large tailings pile. The unoxidized sulfide tailings were taken from under the oxidized layer of the pile.

The waste rock came from a mine in British Columbia, Canada, where the sulfide ore is mined for its silver, copper, and gold content. The material used in the experiment was unprocessed because it was below ore grade. The material was unsized (15 cm x 0 cm) and represented the most acid-producing material from this mine.

Samples of each material were taken at the beginning of the experiment for sulfur determination. Total sulfur was measured using the combustion furnace method. To differentiate the sulfur forms, two acid extractions (hydrochloric acid and nitric acid) were performed. The residues from these extractions were analyzed in a combustion furnace, and the percentages of total, pyritic, sulfate, and organic sulfur were calculated (table 1).

EXPERIMENTAL PROCEDURES

The supply of waste materials limited the experiment to three 100-kg samples of each waste material: one untreated control, one treated with SLS, and one treated with potassium benzoate. In addition to these 100-kg samples, eight 7-kg samples of each material were treated as follows: two untreated controls, a high and low dose of SLS, a high and low dose of potassium benzoate, and a high and low dose of potassium sorbate. The experimental design is summarized in table 2.

For the 100-kg samples, nine 200-L plastic barrels were set up on wooden platforms. Two holes were drilled in the bottom of each barrel, and a plastic bucket was placed underneath each hole to collect leachate. For the 7-kg samples, twenty-four 20-L plastic buckets were used. Each bucket had two holes drilled in the bottom and was positioned over another bucket to enable leachate collection.

Each of the mine wastes was used to fill three barrels and eight buckets with 100 kg and 7 kg of material, respectively. The waste materials were added (without compaction) to their respective containers, and within one week, the experiment began. An enclosed hangar-type building in which the air temperature ranged from approximately 15 to 25° C was used for the experiment.

Each barrel (100-kg samples) designated to receive chemical treatment was treated with 8 L of a 7,500-mg/L solution of SLS or benzoate. These treatments were equivalent to 600 mg of treatment chemical per kilogram of waste material. The barrels designated as controls received 8 L of deionized tap water.

Two of the eight buckets (7-kg samples) of each material were designated as untreated controls. The remaining six buckets of each material received a high or low dose of SLS, potassium benzoate, or potassium sorbate. The high treatment dose was added to each bucket using 1.2 L of the appropriate 3,500-mg/L solution. The low treatment dose was applied using 1.2 L of a 350-mg/L solution. The high and low treatment doses were equivalent to 600 and 60 mg, respectively, of treatment chemical per kilogram of material. The buckets designated as controls received 1.2 L of deionized tap water.

The weekly leaching program began one week after treatment. Tap water was passed through a 0.20-µm capsule filter and a two-beam ion-exchange-resin system before storage in a 2000-L plastic reservoir. Periodic sampling of this reservoir showed the water to be acceptably low in dissolved solids, and the population of iron-oxidizing bacteria was below detectable limits (<18 cell/100 mL). A plastic sprinkling can was used to evenly distribute water on each waste material. The 100-kg and 7-kg samples were leached with 8.0 and 1.2 L of water, respectively. These volumes are equivalent to 2.54 cm of precipitation on the waste material per week.

After the waste materials were watered, they freely drained into the sample-collection buckets for 24 h. Samples from each leachate were taken and the remaining volume was measured and discarded. Samples from alternate weeks were refrigerated for 7 days and combined with an equal volume of a corresponding sample from the subsequent leaching. These composite samples were then analyzed.

Water samples of the leachate from each bucket and barrel were analyzed for pH, acidity, ferrous iron, total iron, calcium, magnesium, aluminum, sodium, manganese, and sulfate. Ferrous iron was detected with a potassium dichromate titration using the sodium salt of diphenylaminesulfonic acid as an indicator. Other metal concentrations were determined by inductively coupled argon plasma (ICAP) spectroscopy. After passing the sample through a cation-exchange resin, sulfate was analyzed by barium chloride titration using thorin as an indicator. Acidity analysis consisted of a fixed endpoint titration to pH 8.3 using a 1N sodium hydroxide solution. Iron-oxidizing bacteria

populations were estimated for the barrels only. The multiple-tube, most probable number (MPN) technique described by (Olem and Unz, 1977) was used.

RESULTS

The following sections cover the results of the three treatment chemicals on the three mine waste materials. Although direct measurements of the bacterial populations were made, the effectiveness of the chemicals was based on leachate water quality. Graphs of acidity concentration and cumulative acid load over time are presented since acidity directly relates to water treatment costs. Sulfate and total iron in the leachate consistently followed the same trends as acidity. The results are summarized in table 3.

Unoxidized Sulfide Tailings

In the 100-kg samples, SLS did not reduce acidity levels relative to the control in the leachate from the unoxidized sulfide tailings. However, SLS totally inhibited the iron-oxidizing bacteria for 8 weeks and continued to keep the bacterial population below that of the control for an additional 14 weeks. The population of iron-oxidizing bacteria in the untreated control ranged from 3×10^6 to 3×10^7 cells per 100 mL. In the 7-kg samples, neither the high nor low dose of SLS had any significant effect on leachate quality, but based on the high percentages of total iron remaining in the ferrous form, the iron-oxidizing bacteria were inhibited for several weeks.

Potassium benzoate treatment did not reduce acidity levels in the leachate from the 100-kg sample but did keep the bacterial population below that of the control for 18 weeks. Benzoate or sorbate were not effective in reducing leachate acidity levels from the 7-kg samples at either dose. However, ferrous iron data indicated bacterial inhibition in all treatments.

Oxidized Sulfide Tailings

In the 100-kg samples, greater concentrations of acidity were leached from the SLS- and benzoate-treated samples than from the control in the first 6 to 8 weeks (fig. 1). Bacterial populations were not inhibited, and ranged from 3×10^3 to 2×10^5 cells per 100 mL. Results from the 7-kg samples showed that all of the treatments increased acidity over control levels in the first 4 to 8 weeks of the experiment with no subsequent difference in acidity levels between treated samples and controls for the remainder of the experiment. Ferrous iron data suggested that no significant bacteria inhibition occurred.

Waste Rock

In the 100-kg samples, SLS reduced cummulative acid loads to 6, 14, and 41 pct of the loads from the untreated control after 20, 36, and 52

weeks, respectively (fig. 2). For the benzoate-treated sample, cumulative acid loads were reduced to 18, 14, and 24 pct after 20, 36, and 52 weeks, respectively. The iron-oxidizing bacteria were totally inhibited by the SLS and benzoate for 26 and 36 weeks, respectively. In the untreated control, the population of iron-oxidizing bacteria ranged from 2×10^4 to 2×10^6.

In the 7-kg samples, the high dose (600 mg/kg) of SLS, benzoate and sorbate kept acidity concentrations below 50 pct of the lowest of the two untreated controls for 49, 21, and 21 weeks respectively (fig. 3).

The low dose (60 mg/kg) of SLS and benzoate reduced acidity concentrations below 50 pct of the lowest control for 9 and 11 weeks, respectively. The low sorbate dose did not reduce acidity levels (fig. 4).

DISCUSSION

The leaching procedure used in this experiment represents an acceleration of actual field rainfall conditions. Although 2.54 cm of precipitation does not seem excessive, the procedure does not allow for runoff or significant evaporation that might occur in the field. The duration of bacterial inhibition for the treatment chemicals may have been diminished by the short period of time that the water was added. This may have increased the amount of chemical that was washed off, however, the treatment was not lost to runoff and may be deposited at a lower position in the sample. Because of these variables, caution must be exercised during extrapolation of the results of laboratory leaching tests to intended field use.

The results from the unoxidized sulfide tailings showed that SLS, benzoate, and sorbate effectively inhibited iron-oxidizing bacteria but did not reduce contaminant levels. In the 100-kg samples, bacterial populations remained inhibited for approximately twenty weeks. In the 7-kg sample, the ferrous iron percentage indicated that the bacteria were also inhibited for several weeks without reduction of contaminant levels. The successful inhibition of the iron-oxidizing bacteria without contaminant reduction indicated that either the bacteria do not play a significant role in the tailings or that the previously weathered oxidation products flushed at the beginning of the experiment masked any observable effect on water quality. To resolve this question, additional tests are being conducted (the procedures used in these tests will be discussed in more detail in the final copy of this paper). In these tests, the six 7-kg samples were extensively flushed with distilled water and dilute solutions of hydrochloric acid to remove any previously oxidized material before the addition of SLS and benzoate. After seven weeks, the iron-oxidizing bacteria have repopulated in the untreated controls but not in the treated samples. Water quality data show acidity concentrations of 2480, 2190, and 3060 mg/L in the leachate from untreated controls; 365 and 378 mg/L in the SLS-treated samples; and 326 mg/L for the benzoate-treated sample.

Results from the oxidized sulfide tailings showed that all of the treatments increased acidity levels in 100- and 7-kg samples. The material was considerably oxidized with 5.81 pct sulfate sulfur and only 0.17 pct pyritic sulfur; therefore, most of the contamination in the leachate was from the flushing of previously oxidized material.

Apparently, the treatment chemicals caused an increased flushing of contaminants. SLS could have increased contaminat flushing by its surfactant properties. Benzoate and sorbate readily form complexes with iron which could result in breakdown of weathered products, thereby increasing contaminant flushing.

Results from the benzoate- and SLS-treatments of the waste rock indicate that both chemicals may be applicable for field use. SLS has reportedly been applied by a mining company in the field, but no reductions in contaminant levels were observed. The blocky nature of the silver mine waste rock permits air to penetrate deeply into the pile. Consequently, in order to inhibit bacteria and reduce contaminant levels, a large portion of the pile must receive the chemical inhibitor and not just the uppermost layer. Actual field tests are needed to determine the utility of bacterial inhibitor application for field use.

CONCLUSIONS

The major conclusions that can be drawn from this study are:

1. Application of SLS, potassium benzoate, and potassium sorbate on highly oxidized sulfide tailings can cause an increased rate of contaminant flushing and do not inhibit the relatively small populations of iron-oxidizing bacteria.

2. SLS, potassium benzoate, and potassium sorbate can significantly reduce the population of iron-oxidizing bacteria when applied to unoxidized sulfide tailings; however, this inhibition of bacteria only results in reduction of contaminant loads in the leachate when weathered products are removed from the material prior to treatment.

3. Application of SLS, potassium benzoate, and potassium sorbate on waste rock can cause significant inhibition of the iron-oxidizing bacteria which results in a significant reduction of contaminant levels in the leachate.

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Table 1. Sulfur Content of Waste Materials

Material	Sulfur form, pct by weight		
	Total	Pyritic	Sulfate
Unoxidized sulfide tailings	20.57	19.73	0.84
Oxidized sulfide tailings	5.98	0.17	5.81
Waste rock	4.07	4.07	-

Table 2. - Treatment of Samples for Each Waste Material

Sample weight, kg	Chemical treatment	Treatment dosage, mg/kg	Volume of water used in weekly leachings, L
100	Untreated	-	8.0
100	SLS	600	8.0
100	Benzoate	600	8.0
7	Untreated	-	1.2
7	"	-	1.2
7	SLS	600	1.2
7	"	60	1.2
7	Benzoate	600	1.2
7	"	60	1.2
7	Sorbate	600	1.2
7	"	60	1.2

Table 3. - Summary of Results

Material	Treatment chemical	Duration of bacterial inhibition for 100-kg samples[A], weeks	Duration of Acidity Reduction[B], weeks		
			100-kg samples	7-kg samples	
				High dose	Low dose
Unoxidized Sulfide Tailings	SLS	22	0	0	0
	Benzoate	18	0	0	0
	Sorbate	Not Tested	Not Tested	0	0
Oxidized Sulfide Tailings	SLS	0	0	0	0
	Benzoate	0	0	0	0
	Sorbate	Not Tested	Not Tested	0	0
Waste rock	SLS	26	34	49	9
	Benzoate	36	46	21	11
	Sorbate	Not Tested	Not Tested	21	0

[A]Length of time population of iron-oxidizing bacteria was inhibited to less than 1 pct of the control.

[B]Length of time leachate acidity concentration was less than 50 pct of the control.

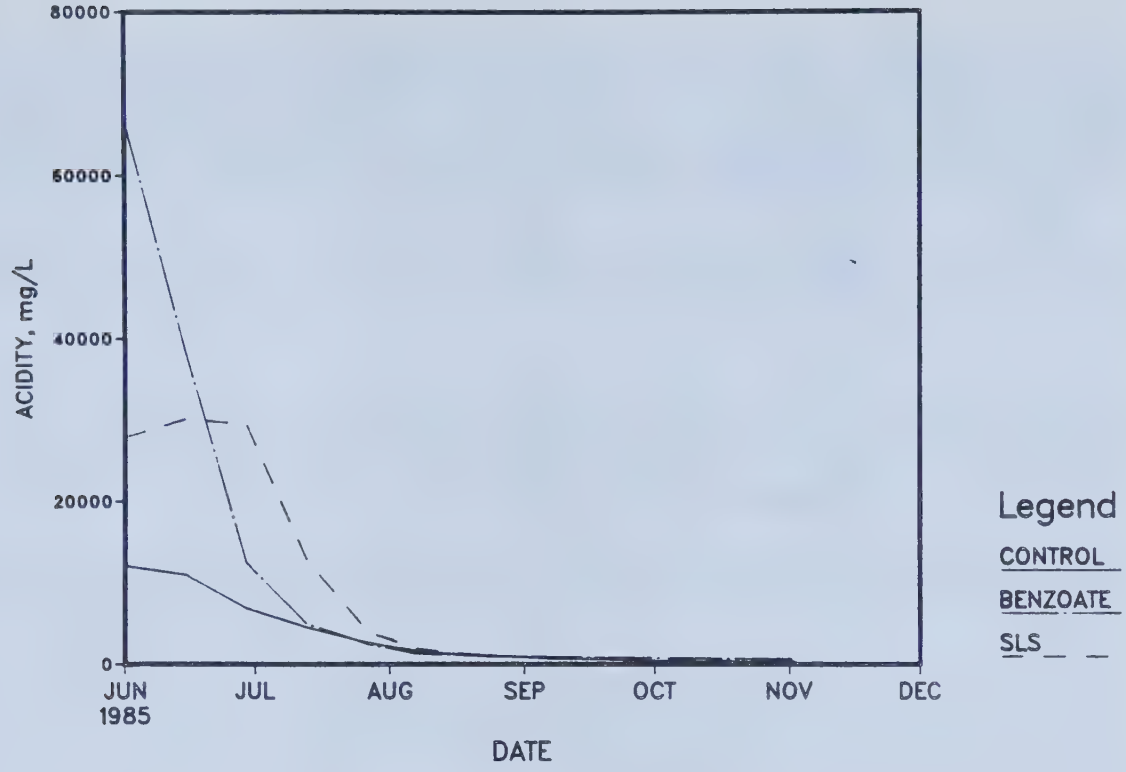

Figure 1. Oxidized sulfide tailings, 100-kg samples.

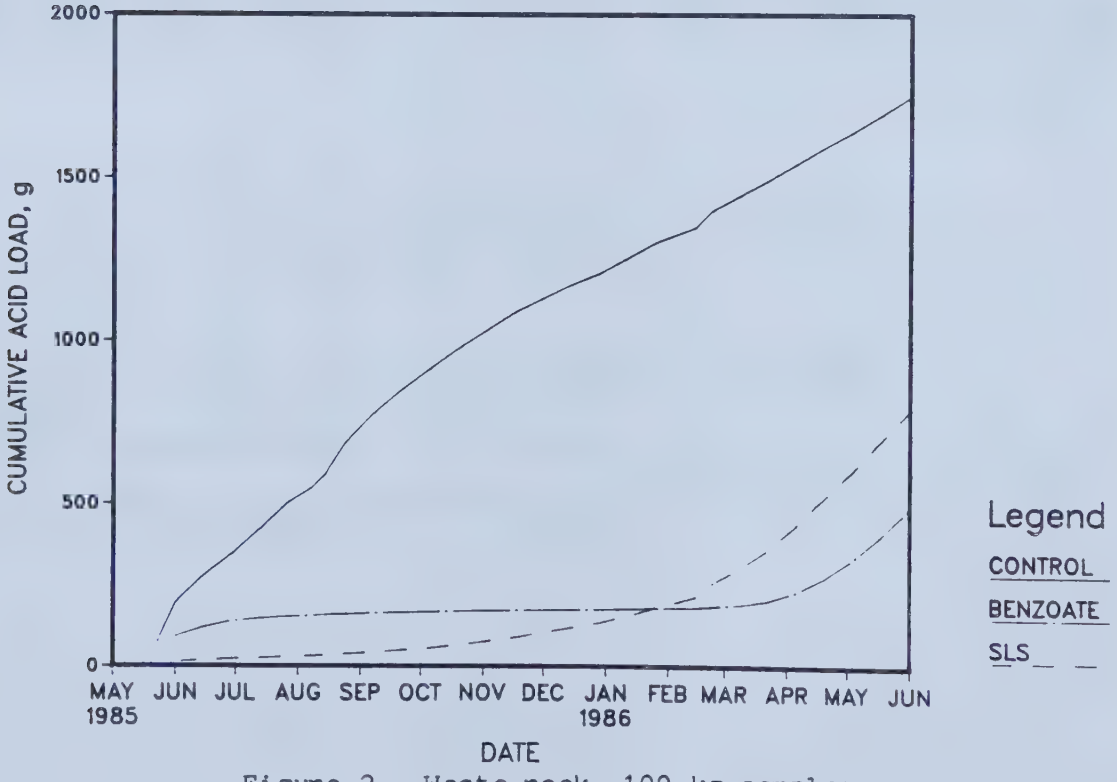

Figure 2. Waste rock, 100-kg samples.

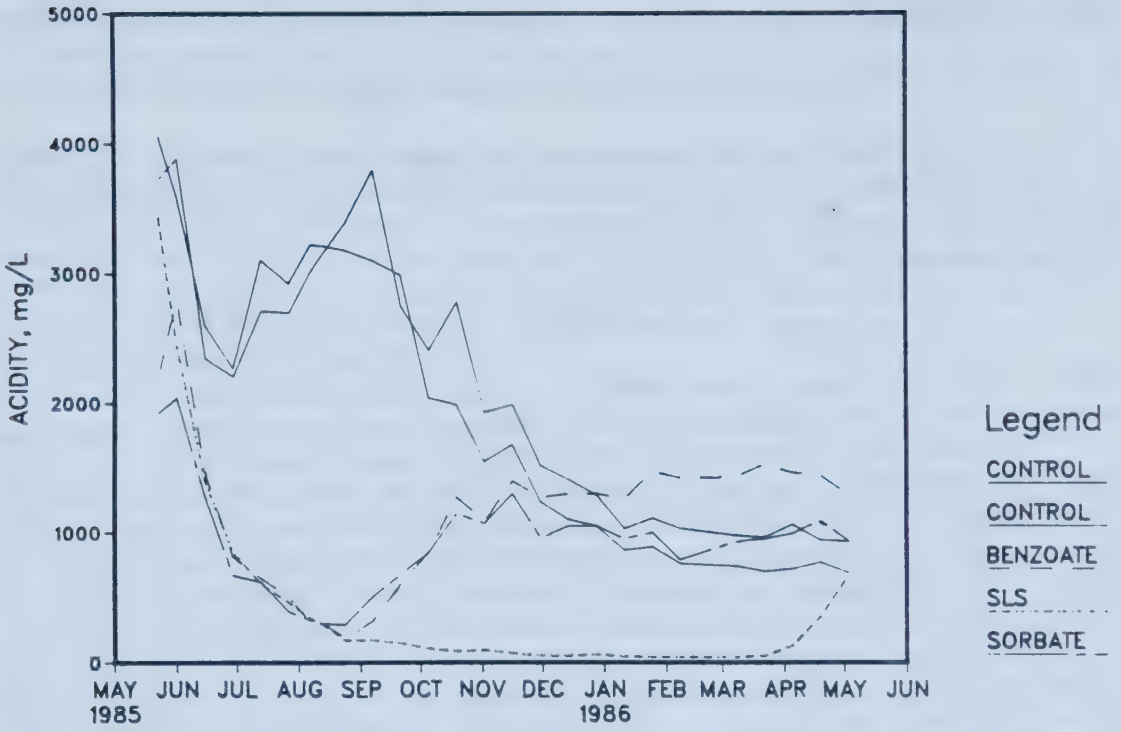

Figure 3. Waste rock, 7-kg samples, high treatment dose (600 mg/kg).

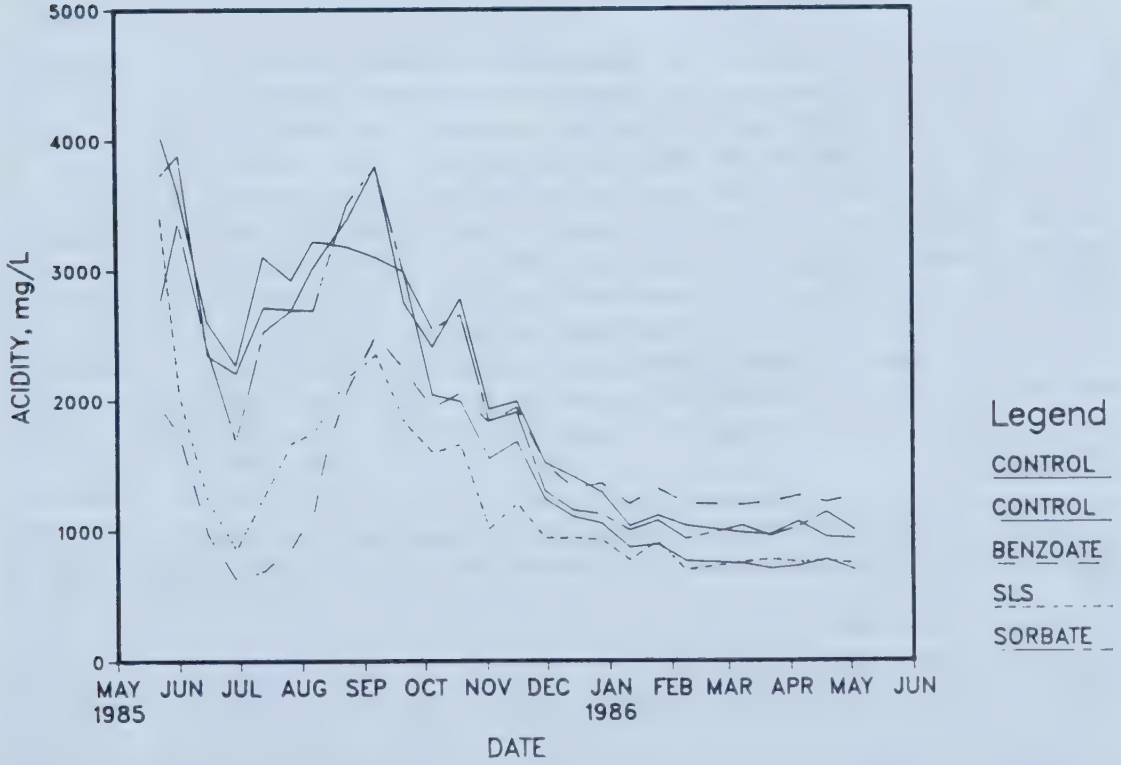

Figure 4. Waste rock, 7-kg samples, low treatment dose (60 mg/kg).

AMELIORATION OF MINE TAILINGS WITH LOCAL PEAT SOILS IN SOUTHERN CANADIAN SHIELD*

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ABSTRACT

Many Canadian mine tailings contain iron sulphides, which are oxidized by microorganisms. This causes extensive acid leaching and consequently contamination of the environment. It is known that, if the tailings are flooded, there is insufficient oxygen dissolved in the water for this oxidation to take place. This method is currently being considered for the prevention of oxidation in certain sites. However it is impractical to flood many old tailings, so we suggest that a self-sustaining anaerobic cover of peat bog will both prevent acid leaching and reclaim old tailings dumps with a natural environment. Part of the methane produced by degradation of biomass is trapped in the peat and prevents both the penetration of oxygen and the movement of water in the tailings.

INTRODUCTION

For a century mining has been one of Canada's major industries, and during this time a vast amount of waste rock, deposited as mill tailings, has accumulated around the mine sites. Many of these tailings have been left unattended for years, and in a considerable number of cases this waste contains iron sulphides such as pyrite and pyrrhotite, which are used by microorganisms, notably Thiobacillus ferrooxidans, as an energy source for growth. This use results in a run-off from the tailings, which is both extremely acidic and also contains soluble sulphate salts of any remaining heavy metals (Moneco 1984). The increasingly stringent regulations for effluents released into the environment require that this acid leaching and heavy metal contamination be controlled.

The US Bureau of Mines was already looking in 1918 for a method to treat acid drainage from coal mines (Tracy 1918); and by 1930 it was realised that exclusion of oxygen prevented this acid formation and the precipitation of iron (Leitch & Yant 1930); but already acid mine drainage threatened to be a problem of national importance as coal resources were increasingly developed. Even at

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

this date the process of oxidation was being questioned, as it seemed to be too rapid to be solely due to chemical reactions, and it was suggested that it might be caused by organisms similar to Thiobacillus thiooxidans (Carpenter & Herndon 1933).

However it was not until 1947 that microorganisms were generally recognized as the cause of the breakdown of pyritic minerals to sulphuric acid (Colmer & Hinkle 1947). Pyrite is found in association both with coal and metal ores, but the generation of acid in tailings of metal mines was not perceived as a problem until after 1960 when several uranium mines were shut down for economic reasons (Hester 1984).

TAILINGS

There are some 500 million tons of acid tailings in Canada covering an area of 9,000ha (Monaco 1984) (Figure 1). The problem is thus vast, especially when it is realized that many of these tailings have been deposited on porous ground because the initial aim was to drain the tails of their liquid, as it was thought to be easier to reclaim the dried material. In addition, the old dams which once held back the tailings slurry, are now broken and incompetent. However, in spite of the length of time since the problem was first understood, no efficient and economic method has yet been found to manage acid leaching.

Iron sulphides, such as pyrite, are formed in sediments by active microbial sulphate reduction. The microorganisms convert the sulphur to hydrogen sulphide, about 90% of which diffuses up to the oxic zone, while the rest is precipitated by iron to form mackinawite initially, which is converted to greigite and then pyrite (Figure 2). Pyrrhotite is formed when pyrite is subjected to higher temperatures. The sulphur is thus continuously cycled through the sediment, and over time, pyrite is concentrated. It is these pyritic and pyrrhotitic formations that have the potential to cause soil acidity when brought into the oxic zone as they provide a growth substrate for chemolithic sulphur oxidizing microorganisms, notably Thiobacillus ferrooxidans.

These organisms are able to derive energy from the oxidation of ferrous iron and inorganic sulphur. The sulphur is oxidized to sulphate (Figure 2) and thus forms sulphuric acid, while the ferrous iron is further oxidized to ferric iron which, either alone or in combination with sulphate, is involved in the indirect attack on sulphide minerals (Lundgren & Silver 1980).

Since the oxidation of iron sulphide is a very inefficient method of obtaining energy the bacteria require a good supply of oxygen (Kuenen & Tuovinen 1981). The depth of an oxidation layer is dependant upon the availability of oxygen for the bacteria, and is controlled by the permeability of the tailings, which regulates the penetration of air or oxygenated water. Oxygen is consumed in

Figure 1. Pouring tailings slurry at Kidd Creek Mine, Timmins.

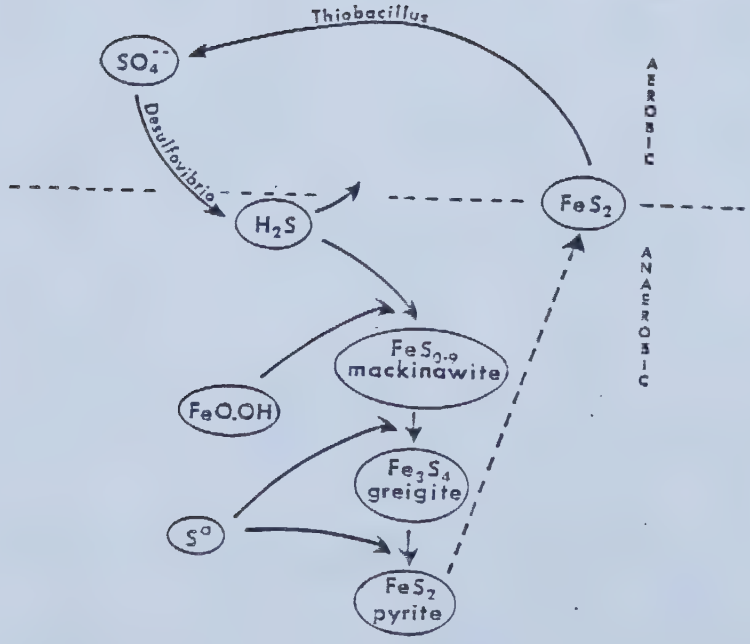

Figure 2. The Sulphur Cycle.

the top layer until the concentration is inadequate to support the generation of ferric ions. With oxygen depleted, ferric ion is then rapidly reduced by pyrite to the ferrous state. Iron hydroxides and/or oxides are then formed and precipitated to form a well defined hardpan, with fresh, unaltered tailings below (Boorman & Watson 1976). This zoning was recently confirmed by Petruk & Pinard (1986) in the Waite Amulet tailings: where there is a high concentration of sulphides in the base, there is a sharp change in concentration at the water table, and there are essentially no sulphides near the surface.

PEAT SOILS

Thus, to eliminate acid leaching oxygen must be prevented from reaching the pyritic tailings. This can be accomplished by flooding, as there is insufficient oxygen dissolved in the water to allow these organisms to grow (Moneco 1984). However, where flooding is not feasible, we suggest that an anaerobic environment can be induced by covering the tailings with a layer of muskeg peat bog.

Muskeg bogs cover about 12% of the land area of Canada, and contain peat more than 60cm thick. They are found in cool, wet environments in mid-Temperate latitudes and are common in the Canadian Shield where many of the mines are located. These wetland bogs have been accumulating throughout the northern Temperate Zone, where there is adequate precipitation, since the ice retreated 5,000 to 10,000 years ago.

Peat itself is formed from the partial degradation of plant biomass. Plants consist of three interlinking polymers of cellulose, hemicellulose and lignin (Brown 1985). Cellulose is the main degradable constituent, and normally, in aerobic terrestrial soils, it is rapidly degraded to carbon dioxide. But in waterlogged soils a consortium of bacteria reduce the cellulose to methane, and this anaerobic degradation is much slower. Impressive accumulations of peat occur when there is an imbalance between the slow degradation of plant biomass in an anaerobic environment, and the faster rate of deposition of the plants detritus (Kurbatov 1968).

We have investigated thirty different bogs from the mining areas of Noranda, Timmins, Sudbury and Elliot Lake. These bogs were characterized by physical, chemical and biological methods to find their suitablility for methane production.

Peat will thus produce an anaerobic milieu through the synthesis of methane by the bog microorganisms. Once the bog is established on top of the tailings, the normal succession of plant growth, death, and partial decomposition should take place and create a self-sustaining bog, which will be viable indefinitely in cool, wet climates, and therefore require no further expenditure.

SPHAGNUM

The most important bog plant is sphagnum. This moss is a bryophyte which typically grows at a pH of around 3, and is ombrotrophic, that is it only requires nutrients from rain or its own detritus. The genus Sphagnum has remarkable powers of water retention due to the large water storage cells which form much of the bulk of the leaves and stems. This produces a raised water table due to the high water-holding capacity and low hydraulic conductivity.

In regions where there is a high rainfall and a moisture-laden atmosphere, there may be sufficient humidity to cause waterlogging and peat formation even outside drainage basins. Where these conditions are extreme peat may even accumulate over the sloping hill sides as well as on flat surfaces, covering the landscape with a thick 'blanket bog'. In drier climates, bogs which are dependant upon precipitation can still develop, mainly in valley bottoms. Such mires are called 'raised or domed bogs' for they typically grow in convex shapes (Godwin 1978).

PRODUCTION OF METHANE

The microorganisms of the anaerobic degradation chain bring about the complete conversion of cellulose to methane and carbon dioxide (Morris 1975). There are two interrelated processes: first the cellulose carbon is oxidized to carbon dioxide and other small carbon compounds, while at the same time hydrogen is produced; and secondly this hydrogen is oxidized to water, and the carbon dioxide is reduced to methane (Figure 3). If sulphate is present

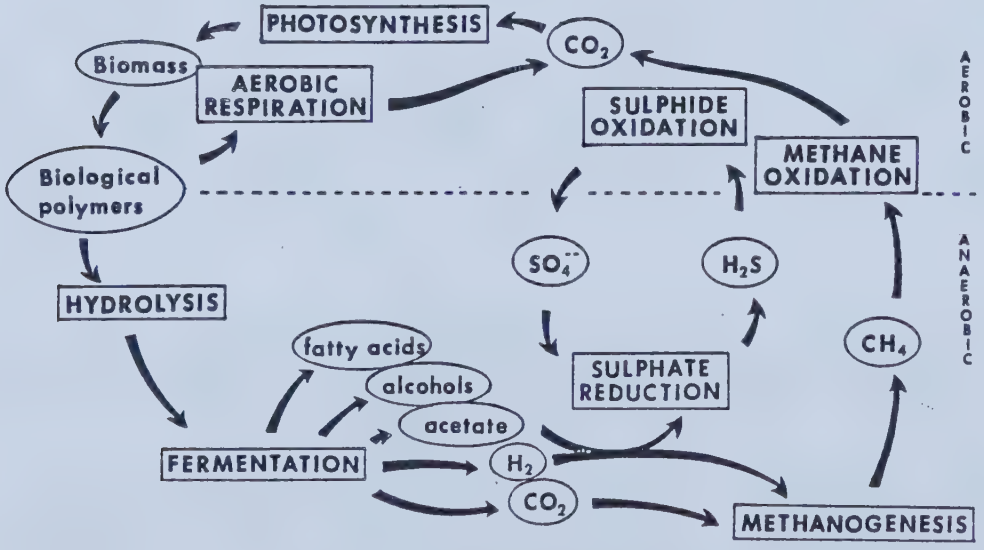

Figure 3. Metabolic pathways in peat.

other bacteria can also act as hydrogen-consumers and reduce sulphate to hydrogen sulphide.

The production of methane from bogs has been know for a long time from the will-o'-the-wisp (ignited marsh gas) that is produced under certain weather conditions. Surprisingly there seems to be little data on size or flux of peatland methane pools (Armentano & Menges 1986), which may be due to the difficulty of measuring the methane. Late last summer we developed, refined and tested a system for measuring methane in situ (Dinel et al 1987). In several bogs near Ottawa the concentration of the methane, and the ratio of methane to carbon dioxide was found to increase with depth.

This methane is trapped in the peat, especially in deeper layers where it is usually saturated to levels beyond that found at normal temperature and pressure. This supersaturation is mainly due to the hydrostatic pressure of the overlying water, similar to that found in lake sediments. Since methane is less dense than air, when a cavity is created or methane-saturated water interfaces with air at the fringe of a bog, methane will be outgassed and driven to the surface through the pore cavities which already contain water. Bubbles of methane may block these spaces when there is not enough energy to push the gas through constrictions. This blocking prevents not only the penetration of any oxygen but also the movement of water and its attendant dissolved minerals (Mathur & Lévesque 1985).

In the past methane production has generally been estimated through laboratory incubation of peat samples from various depths, or from measurement of methane released from the surface. Our initial results show that this does not give the complete picture, since the methane is trapped within the peat. In a small basin bog in the Gatineau we have obtained samples of interstitial gases and water from deep layers where up to 60% by volume was methane. Due to the acid environment of bogs the bacteria produce methane very slowly so it would seem that this methane had been accumulating for tens of years, if not millenia.

While placing the muskeg on the tailings it will be necessary to expose the anaerobic layers to the atmosphere. Initially we did not know whether this would destroy the obligately anaerobic methanogens but preliminary results suggest that, if the peat is kept wet, the anaerobic degradation chain can generally be reestablished so long as there is sufficient cellulose substrate to be degraded into methane.

RECLAIMATION

When tailings do not contain much pyritic rock, it is possible to revegetate them successfully. But the vegetation on old sulphide tailings dumps, such as those of Waite Amulet near Noranda and

Figure 4. Acid leaching at Waite Amulet, Noranda.

Figure 5. Pumping water on to organic cover of pyrrhotite tailings, at Falconbridge Nickel Mines, Ontario.

Nickel Rim near Sudbury, which have been revegetated with heavy expenditure on lime and fertilizer, is very fragile. The acid seepage continues (Figure 4) and slowly percolates up into the covering vegetation and kills not only the plants but also the soil microorganisms. So, although revegetation which allows oxygen penetration may seem at first to be successful, it is actually only a temporary cosmetic measure, because it has little or no effect on the acid leaching and the long term reclamation of tailings dumps, for, as the acidity reasserts itself, the phytotoxic heavy metals are more easily taken up by the plants and cause vegetation die-off. It should be noted however that, unlike mineral soil microorganisms which are very susceptible to metal toxification, peat microorganisms are protected by the ability of peat humus to chelate metal ions (Mathur & Farnham 1985).

A start has been made by Falconbridge Nickel Mines, Ontario to saturate and cover a pyrrhotite tailings dump with organic matter in order to build up an anaerobic soil layer (Figure 5). There are two problems to establishing a peat cover on tailings: one is the actual application of the organic soil, and the other is raising the water table to maintain anaerobiosis during the establishment of the soil.

Most of the old tailings have been drained of the water from the original slurry long ago and both this drainage and later rainfall have caused internal channelling, so that any water applied quickly runs through. This rapid flowthrough does not occur in bogs: the water saturation of the bog, and the gas pressure of the methane prevents penetration, and rain runs off the surface. If we can establish a raised bog on the tailings we hope that it will be able to maintain a raised water table, to ensure that the tailings remain anaerobic.

The establishment of a bog will initially require added organic matter, such as some type of cellulose, for the anaerobic microbiological degradation chain to use as substrate. Once the metabolic cycle has been set up (Figure 3), the slow degradation of the bog plants on death will maintain the bog indefinitely, so long as the rainfall remains adequate.

CONCLUSION

If a self-sustaining active peat cover can be established on tailings dumps it will prevent oxygen penetration by methane production in the peat; it will increase the level of the water table by the growth of sphagnum; and it will chelate many of the metal ions in the peat humus. It will also solve a perennial environmental problem of the Canadian mining industry caused by acid leaching.

ACKNOWLEDGEMENTS

A.B was funded by Canada Energy Mines and Resources.

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BIOLOGICAL POLISHING OF ACIDIC SEEPAGE CREEKS

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Ecological Engineering and Biological Polishing methods are being developed on a pyrrhotite covered tailings area. INCO started the research work with the Reactive acid tailings (CANMET) program in 1985. This presentation summarizes the chemical, physical and biological results relating to the characteristics of a seepage creek emerging from a tailings dam.

In 1985, a detailed description of the behaviour of the seepage creek was carried out to attempt a synthesis of ongoing chemical and physical processes. Nine stations at 50 m intervals along the creek were monitored for chemical and physical data (July, August and September), and the biology of the stream was described.

It was found that organic matter (living and dead) in the seepage creek appears to provide a catalytic surface for precipitation of iron hydroxide from the water. Steady iron removal occurs over the upper 250 m of the creek. The hydraulic retention time of the creek water increases as the water enters a broad expanse (= pond) of a grass. A 6.5-fold reduction in total soluble iron occurs across this area (to a level of 0.2 ppm) along with a concomitant drop in pH of 2 full units. The latter acidification resulted in a re-solution of metals.

In 1986, the number of stations monitored was reduced, but the frequency of sampling was increased to obtain confirmation of the previously described processes (Figures 1 and 2). Containment structures were built at the foot of the seepage to contain the acidic water. Preliminary experiments to establish acidophillic wetland plants were carried out.

Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987

A self-maintaining treatment system for seepages has to consist of a two-step biological polishing system. At the head of the seepage, an alkaline or neutral ecosystem has to remove iron, and this should be followed by an acidic ecosystem which will remove dissolved heavy metals and produce reducing conditions.

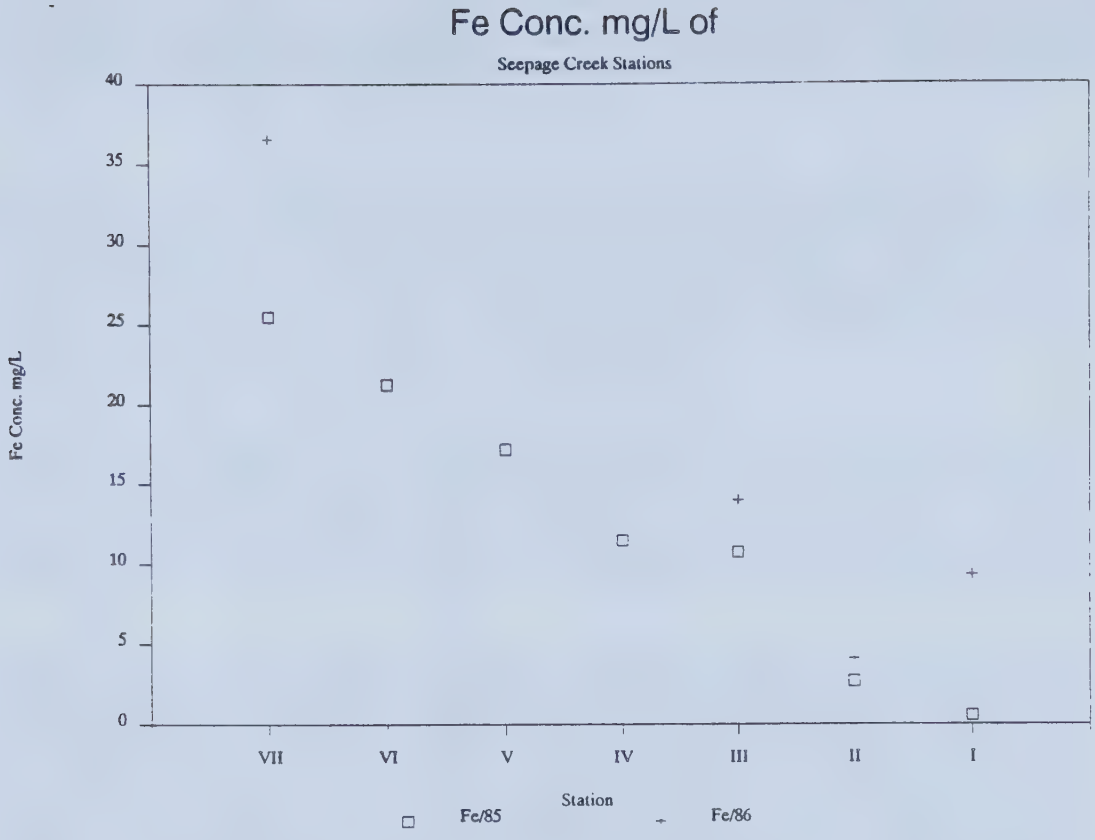

FIGURE 1 The concentration of iron is reduced from the origin of the seepage at Station VII gradually to Station III. Between Station III and I, the grass retention pool is serving as a final polishing system. The same trend was identified for two years.

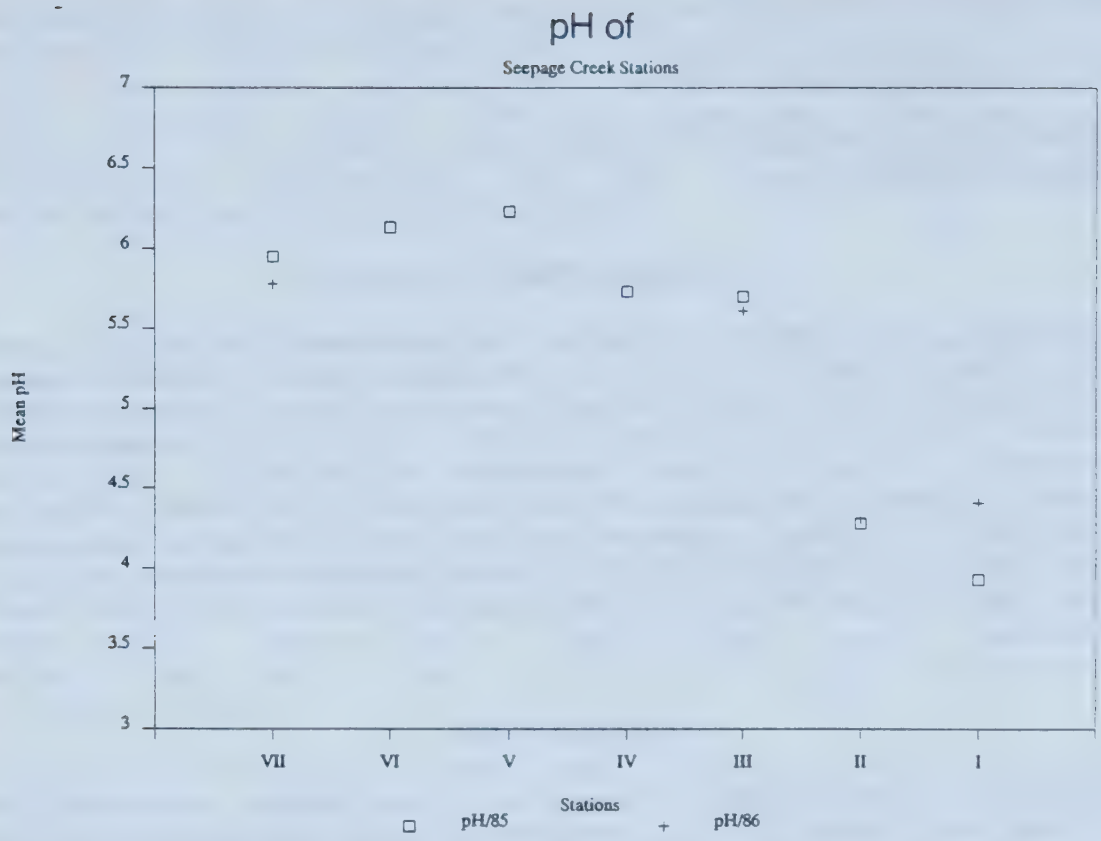

FIGURE 2 At the origin of the seepage, the water emerges in the neutral range at Station VII and as oxidation occurs over the course of the seepage creek, the water acidifies to pH 4. The trend persists, confirmed by data collected over two years.

THE VISUAL IMPACT OF RECLAMATION*

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ABSTRACT

Landscape Architects believe that reclamation specialists must give priority to visual resources as an integral part of rehabilitation and impact mitigation programs. The visual "fit" of a rehabilitated site with its adjacent landscape is a critical measure of success. The Trans Canada Highway Twinning Project in Banff National Park is presented as a demonstration of some landscape architectural methods used to visually integrate disturbed sites with the natural environment of this world heritage area.

INTRODUCTION

Landscape Architects can be important members of reclamation teams, for they are trained to go beyond the purely technical aspects of the challenge to include the art of landscape re-creation in the holistic sense. Although everyone deals with the visual environment, within the general context of aesthetics, only Landscape Architects presently verbalize and objectively assess it as an integral part of the reclamation process.

Aesthetics is a word used to describe the philosophies and principles of determining the beauty in nature. It is not an additive but an inherent quality of all things, and it is the Landscape Architects who are generally responsible for ensuring that aesthetic quality is identified and used in a manner which will make a positive contribution to the visual fit of project site and landscape.

Landscape Architects believe projects should be planned, designed and implemented in a manner that compliments the environment and adjacent land uses. Visual parameters (aesthetics) must therefore be considered as equal in importance to functional and environmental parameters.

This paper is presented to demonstrate the importance and

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurention University, Sudbury, Ontario, June 7-11, 1987.

role of the visual component in reclamation by reviewing a landscape design process and by presenting examples of reclamation projects involving Landscape Architects on the first two phases of the Trans Canada Highway Twinning in Banff National Park, Alberta. These two phases begin at the park entrance gate and proceed westward for twenty-seven kilometers to the Sunshine Ski Area interchange west of Banff townsite.

LANDSCAPE DESIGN PROCESS

For Landscape Architects, landscape design is an art form governed by the earth sciences. It requires an understanding of, and the ability to work with, many other professions.

A basic design **principle** of Landscape Architecture is that man-made Landscapes can be successfully integrated with natural environments. To accomplish this, many factors need to be considered. These include economic, operational, ecological, recreational and aesthetic values, as well as construction and maintenance considerations.

Landscape Architects have been involved both as team members and singularly in many different aspects of the Trans Canada Highway project which directly relate to reclamation and visual integration (aesthetics). These include;

public presentations
environmental assessments
roadway alignment
borrow pit design and reclamation
contour grading
reclamation demonstration plots
topsoil management
planting seedlings vs relocated vs nursery stock
creek relocation
Park road rehabilitation
project supervision and contract management.

Generally the landscape design process proceeds from the large scale environment to the site specific problem. This enables designers to include regional and localized **parameters** in the development of site specific solutions.

The process of landscape design is very similar to engineering design, as both are based upon thorough analysis and the application of proven **techniques**.

When I refer to **principles, parameters, and techniques**

I am highlighting a system which allows Landscape Architects to divide the tasks of landscape design into identifiable components.

Principles are defined as those elements which embrace Landscape Architectural concepts as they apply to the natural environment. Principles are "Statements Of Intent" and precede any design or planning work. For example, a principle may be stated as: "The achievement of aesthetic, recreational, and land rehabilitation objectives will be undertaken with due recognition of environmental, safety, cost and timing objectives."

Parameters are the major, or controlling factors which may effect the development of design options. Collectively parameters are the "Terms Of Reference" which make it possible to successfully achieve the overall intent. An example of a parameter would be: "To identify patterns and significant elements of existing landscapes and describe their susceptability to impact by development."

Techniques are methods employed by Landscape Architects to design, implement, and maintain the landscape in a manner consistent with the stated principles and parameters of the project. An example of a technique is contour grading to reflect the natural landform.

When implementing the landscape design process on a specific project such as the Trans Canada Highway within Banff National Park, the primary aims and contributions of Landscape Architects were to:

1. Create a roadway environment which reflects the natural character of the park surroundings;

2. Increase the aesthetic quality of roadway features;

3. Accommodate functional and environmental concerns identified by other disciplines;

4. Reduce the visual and terrain impacts of past and proposed roadway construction and;

5. Reduce long term maintenance requirements;

These aims were in accordance with the policies, guidelines and concerns of the Government of Canada as specifically expressed by Environment Canada-Parks, Public Works Canada and the federally appointed Environmental Assessment Review Panel. The realization of these aims has helped to create a roadway which fits the park

landscape in a natural way and is a pleasure both to look at and to drive.

CONE OF VISION

One of the unique challenges which must be addressed in the development of roadways is the relationship of landscape elements with the road user or driver. This individual views the landscape from a moving perspective and not a stationary one.

Successful visual integration of a road right-of-way must recognize this fact and note that for the most part highway users see the road through the windshield, travelling at highway speeds. This mode of observation results in a cone of vision which narrows with each increase in speed making subtle grade changes difficult to comprehend particularly when they are on the edge of the right of way.

In order to establish what drivers see at various speeds, research has been undertaken to determine the various changes in the horizontal angle of vision as it relates to speed. At zero kilometers per hour, the cone of vision is approximately 180 degrees. As speed increases this angle is narrowed as follows:

@ 50 kph the angle of vision is +/- 90 degrees
@ 80 kph the angle of vision is +/- 55 degrees
@100 kph the angle of vision is +/- 40 degrees

At the same time that the angle of vision decreases with speed, the point of concentration increases in distance and the focal point recedes. (figure 1) For example: at 50 kph the focal point is approximately 230 meters distant while at 100 kph the point is 550 meters distant. Objects located at the periphery of the cone and further from the road edge than approximately 200 meters will not be seen by the driver and very well may have a distracting influence. Clearly then to take advantage of an object to be viewed the road must be directed at it and the object must be able to be viewed within the cone of vision for the design speed of the road.

Using the knowledge developed in the cone of vision studies and combining this with an understanding of landform allows designers to recreate naturally appearing landscape forms.

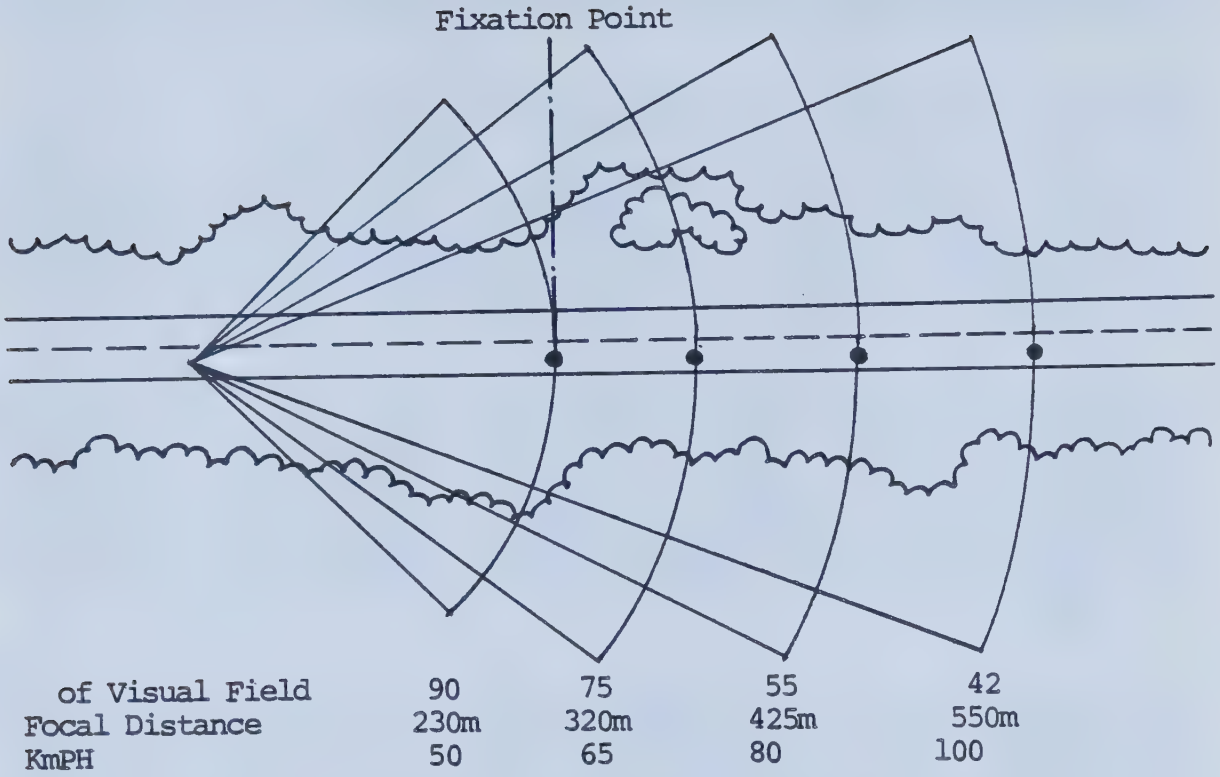

Figure 1 - Cone of Vision

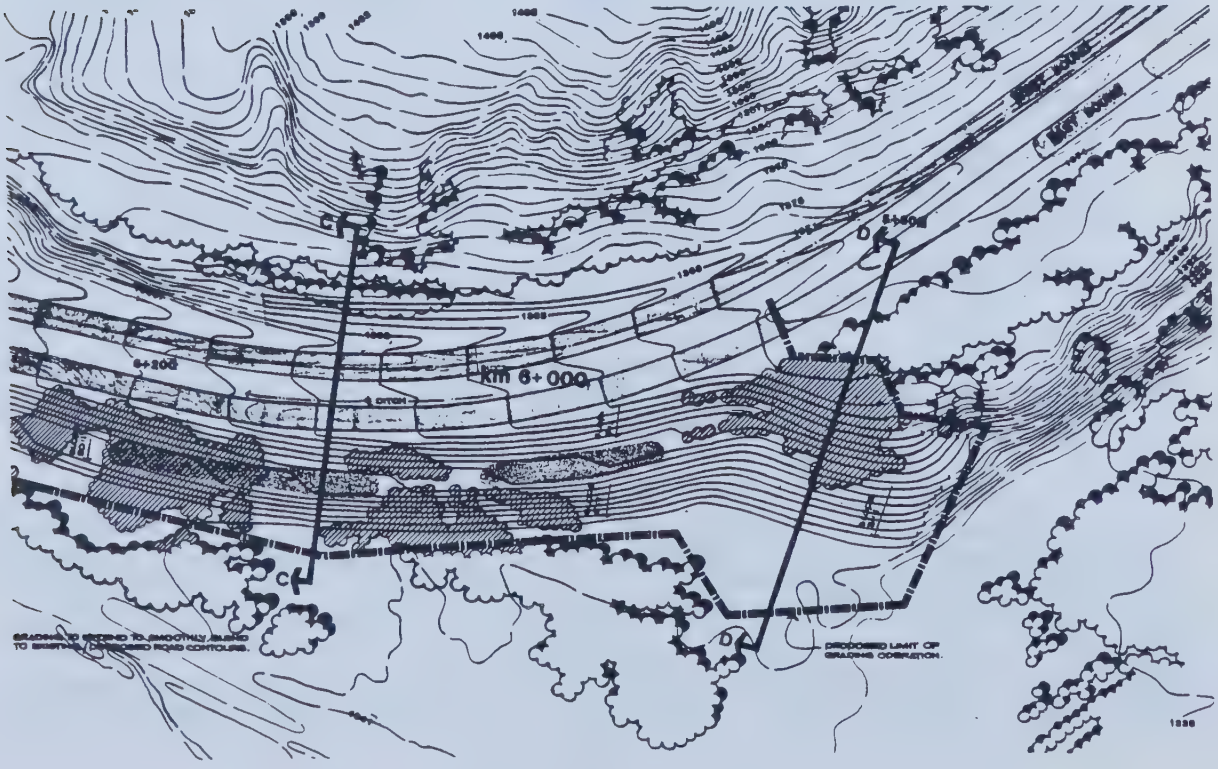

Figure 2 - Contour Grading

PROJECT EXAMPLES OF VISUAL INTEGRATION

Two examples of Landscape Architectural projects undertaken on the Trans Canada Highway in Banff will be presented to illustrate the thesis presented thus far. They are Contour Grading and Healy Pit development. Both included team approaches to problem resolution with the visual component having equal importance with other components.

CONTOUR GRADING

The usual practice of grading road slopes is to build them to rigid engineered standards meeting pre-determined criteria. This, however, does not recognize the "aesthetics" or inherent qualities of the surrounding landscape and often leads to visual problems.

The final shaping or grading of the right-of-way can be the major factor in achieving and aesthetically pleasing and visually successful roadway. Unnatural slope treatments are extremely difficult to camoflage and may in fact retard regeneration thereby resulting in long term visual impacts. The nature of the transition between artificial and natural landforms can either promote a gradual change in vegetation through plant invasion eventually obscuring the right-of-way cut or fill, or it can result in a permanent edge easily seen from a distance and with long term visual and maintenance problems.

Contour grading is the art of analyzing the existing grades in an area and translating these into design grades for the project. To be successful however, existing grades quite often need to be visually exaggerated when interpreted on to the man-made slope to create the desired image. Small draws, for example, are made larger when pulled into the slope in order that they can be more easily constructed and readily seen from the roadway. (figure 2)

Contour grading should be completed during the sub-grade construction stage. This will allow the material to be integrated into the roadway embankment and therefore aid in the total material requirements for the project. At km. 4 of the trans Canada Highway, for example, contour grading was able to contribute many hundreds of cubic meters of suitable fill material to the roadway embankment. When completed at the end of the project contour grading materials usually need to be handled more than once, involve more types of equipment and very often need to be wasted. This extra work is also more expensive with limited positive aesthetic gain.

Contour grading usually involves the principles of slope rounding as well as slope re-shaping. Slope rounding is the curving of the tops and bottoms of the slope to a specific radius formula. It is generally specified and completed as part of the roadway construction where as contour grading itself is most often done by force account or prime cost allowances.

Both of these techniques were used on the development of the major borrow area for the Trans Canada Highway project, the Healy Pit

HEALY PIT DEVELOPMENT

Healy Pit existed before the twinning project was conceived. It had been required for the original highway construction and had been in use for a number of years as a borrow area for the park and as a waste and storage area. It is located at km. 27 on the north side of the highway at the Sunshine Ski Area intersection. The land around the pit was known to house a large population of elk who were in need of replacement habitat for that which would be lost due to highway construction. A proposal was made to expand the existing pit and extract more gravel thereby impacting the area even further. The initial review of the project by Environment Canada Parks, prior to any planning and design was that the extraction of the type envisioned would result in un acceptable long term impacts that would persist for fifty to seventy-five years to wildlife and aesthetic values. The project was rejected. Following the initial rejection, Landscape Architects were given the opportunity to address the problem and develop a design solution which accounted for all concerns.

The "Landscape Architectural Principle" was then to create a more expansive elk range by reclaiming the old borrow area and by developing a new area of sufficient size to provide the required amount of gravel and yet be rehabilitated to suitable elk habitat. The team approach was used. Environment Canada - Parks established the "Parameters" for the requirements of the elk, Public Works Canada supplied the borrow requirements and the test logs for the borrow analysis and the Landscape Architects designed the borrow area to meet the given parameters. These included the clearing of some three hectares of forest, the removal of about 30,000 cubic meters of overburden and the extraction of over 400,000 cubic meters of gravel.

The "techniques" used to create the design included a

thorough site analysis to determine landform characteristics, and viewsheds; an analysis of the test logs to determine the best areas for extraction of the gravel resource and the integration of this data with the requirements for elk habitat. Conceptual ideas were generated to graphically illustrate the overall character desired for the borrow area. These were then reviewed with respect to the anticipated operation of the pit and an extraction plan prepared. This plan was directed specifically at maximizing the use of the gravel resource and maximizing the opportunity to create a naturally appearing area of elk habitat. The result was a series of seven interconnected cells each sized to the environmental requirements for elk and each shaped to take advantage of the location of the gravel. Plans prepared included:

-inventory and analysis
-phased extraction drawings
-borrow area rehabilitation (figure 3)

These were then reviewed by a series of committees and the final approval was given to proceed. What started out as an outright rejection of an idea now had enthusiastic support as the results were predesigned to be positive and make all participants winners. During construction regular monitoring took place by all concerned and direction given as required to account for changes in site conditions.

Once the pit had been excavated and all material uses accounted for, the overburden was replaced and the area contour graded to the desired landscape forms. Contour grading was done under the guidance of the Landscape Architects working on the project. It allowed for the burying of rubble and debris, and the trimmming of slopes to minimize erosion. The area was then dry seeded with a palatable grass mixture, fertilized, planted with trees in selected locations and left to allow nature to take its course.

The entire process of extraction and rehabilitation had taken just over two years and although the grass seeded last fall has not become established as yet, the prospects are excellent and everyone involved is pleased with the results. Within a few years the area will return to a very natural site that visually integrates with the surroundings and with little evidence that it was significantly altered by man.

The original "principle" of extraction to meet a specific environmental objective will have been met once the area is firmly established and being used by elk. I have every belief that this will occur over the next couple of

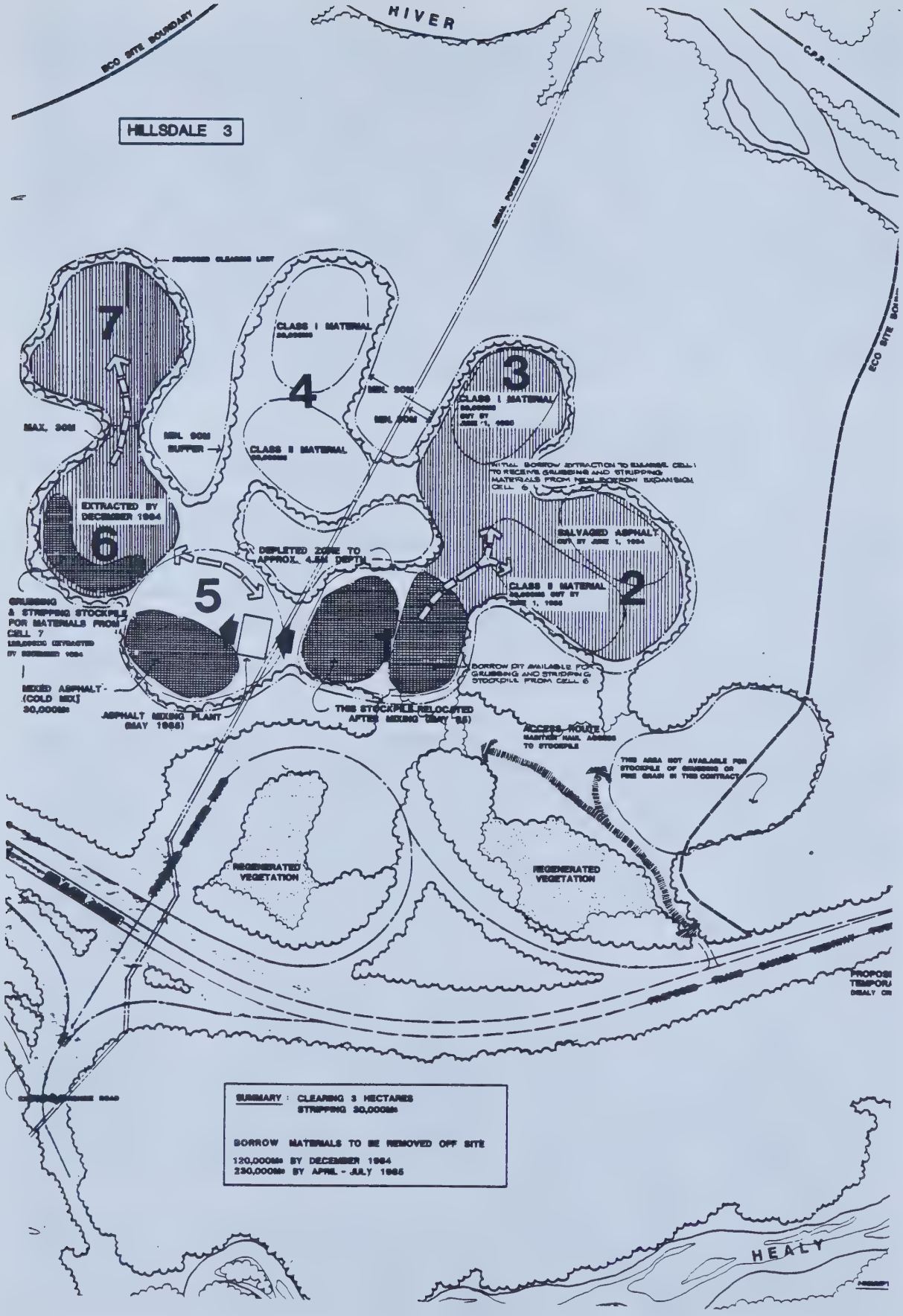

Figure 3 - Healy Pit Reclamation Extraction Plan

years. What was once envisaged as fifty to seventy-five years of detrimental impact will have been reduced to less than five years during which time the area has changed from one landscape function to another yet remained visually attractive as a natural site.

One positive turn of events was the discovery of consistent sources of ground water near the surface. Although the ponds only exist for the summer, they add greatly to the ability of the area to support elk.

CONCLUSION

Reclamation has come a long way in the past few years. Not long ago, I contacted a Provincial component of the Canadian Land Reclamation Association to enquire about the importance of Visual Resource Management in reclamation projects. I was told, quite emphatically, that visual concerns were not a priority. However, with the increases in tourism and an increased awareness and pride in our surroundings, the visual impact of reclamation is now an integral part of most projects. Indeed, Landscape Architects were the first consultants to be commissioned as team members for the development of the next fifty kilometers of the Trans Canada Highway in Banff National Park. Additional team members will include wildlife and fisheries biologists, geologists, hydrologists, botanists,and other specialists. The projects preseneted in this paper provide a brief introduction to Landscape Architecture and its contribution to reclamation. The future successes of our collective efforts will depend upon an holistic approach to design, development, and reclamation of landscapes. The visual "fit" of our work will be an important measure of its success.

This is particularly important to the ultimate success of the twinning of the Trans Canada Highway where all components must be carefully integrated within the context of the Nation's highway in the Nation's first National Park.

LANDSCAPE ARCHITECTURE: CONTINUING INVESTIGATIONS INTO CREATIVE SITE DESIGN FOR SURFACE MINING AND POST MINING LAND USE*

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ABSTRACT

Land reclamation requires creative, cost effective, and efficient solutions. Thus the primary site design and environmental planning professional, the "landscape architect: and their closely allied professionals have become involved in surface mining and reclamation. Their incorporation into surface mining and reclamation followed three phases: (1) the abatement/make-it-pretty phase (2) disease/cure dilemma phase (3) planned post-mining development phase. Today, Many landscape architectural firms have extensive expertise to examine surface mining processes, industrial program requirements and environmental constraints to creatively derive a set of specific physical site solutions that benefit the surface mine operator (increased profits), benefit the land owner (highly desirable post-mining landscapes), satisfy public concerns (fit into comprehensive land-use environments) and meet governmental regulations (health, safety, and welfare). Creative site plans for the post-mining landscapes have been developed for housing, agriculture, wildlife, forestry, recreation, scenic beauty and for second mining. These site plans are not generic; instead, each site plan has a unique form-giving signature that specifically addresses client's needs and environmental concerns.

Additional Key Words: Landscape architecture; post-mining land-use; site planning.

Generating creative, effective and efficient solutions to post-mining land-use issues is a major surface mining task. However, some surface mine operators, governmental employees and surface mine land owners are unfamiliar with opportunities to create usable land. All too often they perceive land reclamation as a one-dimensional technical issue to restore vegetation production. Actually land reclamation is a multi-dimensional development activity where the land is converted from a mining environment to another usable landscape environment. The landscape development choices are endless.

To investigate the potential of the land, the profession of landscape architecture has been readily incorporated into surface mining and

*Presented at Third Annual American Society for Surface Mining and Reclamation, March 18, 1986, Jackson, Mississippi and at the Twelfth Annual Meeting, Canadian Land Reclamation Associaiton, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

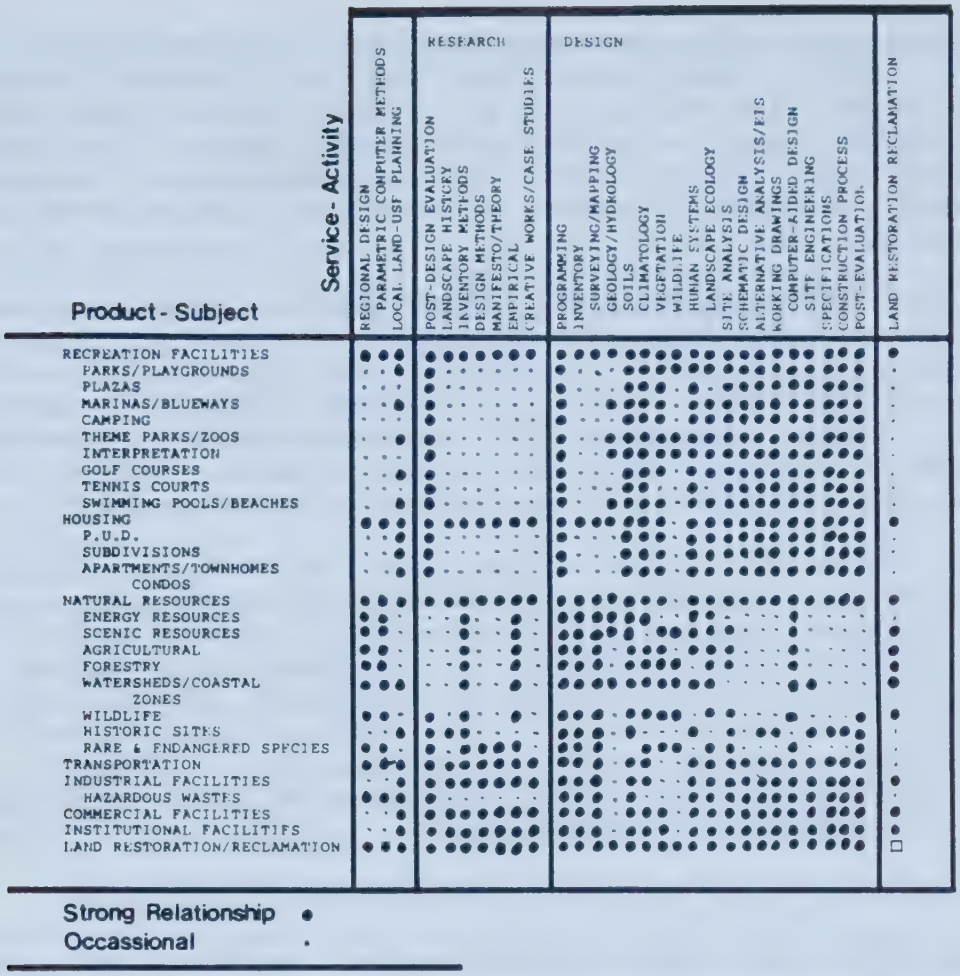


Table 1. This table depicts the existing relationships between the services and products in landscape architecture. Notice the broad range of products and subjects.

post-mining land-use design. These services encompass any object designed, placed, conserved or preserved upon the land, water and air (Table 1). 1986 ASLA (American Society of Landscape Architects) Members Handbook (1986) defines this service as landscape architecture. Many landscape architects and their associates are rigorously trained to prepare surface mining permits, site analysis, impact documents, economic extraction plans, technical working drawings and can prepare a variety of post-mining land-use plans. In preparing plans, geotechnical engineers, plant ecologists, wildlife biologists, soil scientists, planners, hydrologists, and behavioral scientists may be incorporated into an interdisciplinary team to address specific design issues.

While many members may comprise an interdisciplinary landscape architectural team, not just anyone can call themselves a landscape architect. In many states, the landscape architect must have a qualified recognized landscape architectural degree, qualified professional experience and must pass a rigorous national examination to earn the title of landscape architect. In many states, to profess

to be a landscape architect and not hold legal registration is against the law. Such requirements are necessary because landscape architecture and land reclamation are serious issues that have an immediate effect upon the health, safety and welfare of the public. Land reclamation is much more than planting shrubbery on a hillside - yet landscape architectural design services were slow to permeate the surface mining industry.

Prior to the 1960's, professional design services were not readily sought in the resource extraction of surface mined lands. The surface mining industries were very independent. The typical attitude among operators and land owners was to hire a minimal amount of professional services. However, before the 1960's design professionals were active in reclamation efforts. For example Elliot (1925) reviewed issues concerning land reclamation and the landscape architect.

Since the 1960's the surface mining industries have tended towards greater interconnectiveness with broader environmental site planning issues and extensive post-mining design issues. Thus the primary site planning and site design professional, the "landscape architect" and their associated consultants have become involved in surface mining and reclamation. The incorporation of the landscape architectural team into surface mining has followed three phases: (1) abatement/make-it-beautiful phase, (2) disease/cure dilemma phase and (3) planned post-mining development phase.

ABATEMENT PHASE: LANDSCAPE ARCHITECTURAL MISCONCEPTIONS

During the 1960's and 1970's growing public awareness and various governmental legislation resulted in reclamation laws and a stricter permitting process. Professional design teams were utilized as a means to jump the governmental hoops and create beautiful drawings to illustrate how nice the landscape would be during and after the mining operations. Professional input was often perceived by the operator and land owner as an expense to appease governmental and local concerns. Once local concerns were abated and a mining permit was obtained, the plans created by the team were often ignored.

DISEASE/CURE PHASE:

Many registered landscape architects hired to create beautification plans for surface mines noticed unaddressed surface mining issues. Reclamation plans "the cure" prepared by misguided governmental policies were often as bad or even worse than the surface mining activity "the disease". Many reclaimed landscapes were poorly designed. In a recent issue of Landscape Architecture, Dorhney (1984) describes these concerns. Recently, "60 Minutes" (a television news magazine) alerted the public concerning the misapplication of reclamation practices. During this phase, experienced reclamation professionals applied their design methods skills to reassess reclamation goals, perform complex and intricate analysis, and proposed design solutions which generated optimum post-mining landscapes.

GROWTH OF THE PLANNED POST-MINING DEVELOPMENT PHASE

With the growth of this phase, real functional design problems were being resolved. The design of the landscape was not left to chance. many clientele needs associated with surface mining were satisfied. The list of clientele includes: regulating governmental agencies, surface mine operators, land owners and the public. For example, Tony Bauer (1970, 1966, 1965) noticed that one could save the mine operator and the land owner post-mining development expenses by generating the proper forms intended for a specific post-mining land-use such as housing. He described ad hoc post-mining landscapes which were supposed to be intended for housing: yet these landscapes were completely unsuitable for housing. The landforms made development costs prohibitively expensive. Bauer maintains that without incurring extra land handling costs, the site could have been developed in a highly suitable manner for housing. The objective is to utilize the active earth moving process of mining to generate forms that are conducive to housing. Bauer (1983, 1982a) states that the earth moving process can also be advantageous for creating landscapes for wildlife. To address the landform process, Bauer (1982b, 1968) hosted and edited conference proceedings concerning landform design in surface mining.

In other instances, design teams have assisted governmental agencies to avoid needless conflicts between surface mine operators and the public by identifying and developing the resource in an organized and planned manner.

The activities of Bauer and others (Dietrich 1986b, Baxter 1969, Jensen 1967, Johnson 1966b, and Schellie and Rogier 1963) separate the design team approach from a single discipline approach. A single discipline approach is based upon a particular body of knowledge concerned with describing the physical universe (empirical); while the design team is also versed in the act of doing. What a team does is as important as what each team member knows. Design is both an art and science. The design team not only addresses the description of the environment but also the meaning and values associated with non-scientific, value ladden questions such as, "What should we do?" and "What is the best or optimum solution?"

The reclamation team seeks to creatively solve land-use problems and generate inventive site plans for post-mining landscapes. They analyze a site for its development potential and create conceptual plans. Design works include development plans for housing, industry agriculture, wildlife, forestry, recreation, scenic beauty and for second mining.

For example, housing design, which incorporates post-mining landforms, is a complicated effort. There are many factors to consider. Craig Johnson (1966a), a landscape architect at Utah State University, published a paper to assist post-mining operation patterns. Dennis Mersky (1985), describes a case study where a contour coal mine can be utilized for small scale local housing. Burley (1985) has examined

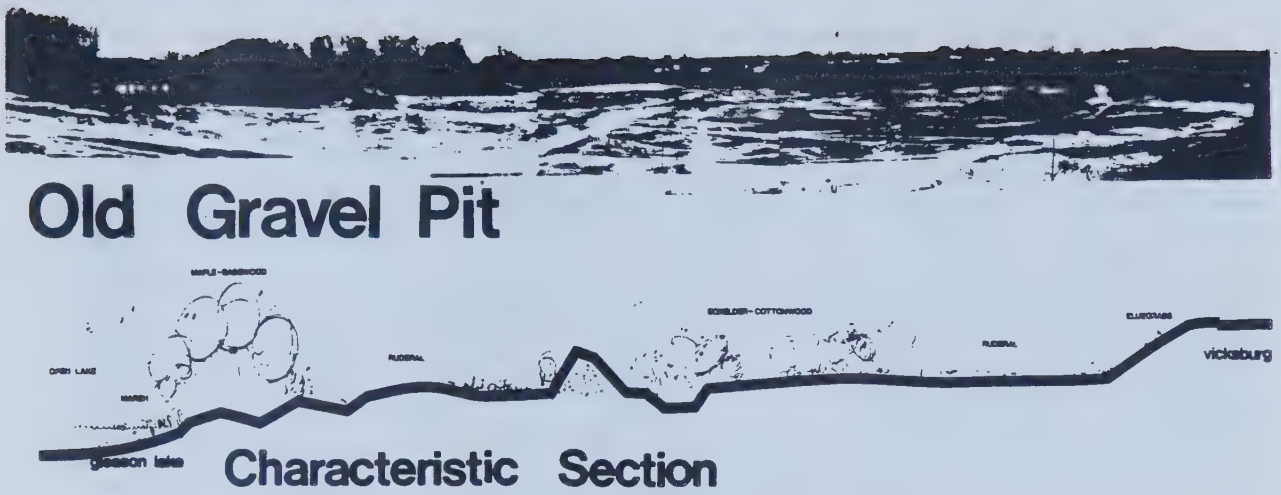


Figure 1. This figure illustrates the pre-development condition of an old gravel pit.

case studies to determine the optimum configurations for post-mining housing developments upon old sand and gravel pits. Carmen (1981) describes the use of coal benches for housing.

Many professions work with the design team to develop a post-mining site for housing. Cimarron Ponds, a townhome development in Plymouth Minnesota and recent Minnesota Chapter of the American Society of Landscape Architects (1981) design award winner, is a planned residential community placed upon an abandoned gravel pit (figure 1). The design was sensitive to the needs of the city, developer, nearby residents, home buyers and wildlife, creating a desirable liveable space for humans and other animals (figure 2). The project incorporated the services of several landscape architects, engineers, biologists, and planners.

Some landscape architects, wildlife biologists, and plant ecologists specialize in developing post-mining sites for wildlife. They are involved in both research and design. In a recent series of research studies, Burley and Hopkins (1984) state that the patterns for abandoned coal and some surface uranium mines often generate landforms ideal for many types of avifauna habitat (1984 Minnesota Chapter of the American Society of Landscape Architects Honor Award). Several papers concerning the design merits of gravel surface mines in a recent wildlife values in gravel pits symposium (Svedarsky, 1982). Burley (1983) describes a post-mining case study utilizing habitat models to design for wildlife. Some design teams have won awards for their wildlife designs in post-mining landscapes.

Since many design teams have extensive experience establishing vegetation in harsh environments and in newly created landscapes, it is not surprising that these design teams would design post-mining landscapes for agriculture. At a recent American Society of Landscape Architects national meeting, Sarah B. Lowe (1985) presented a project design prepared by W.E. Coates Limited Landscape Architects. The project concerned the mining and redevelopment of a Canadian sand and

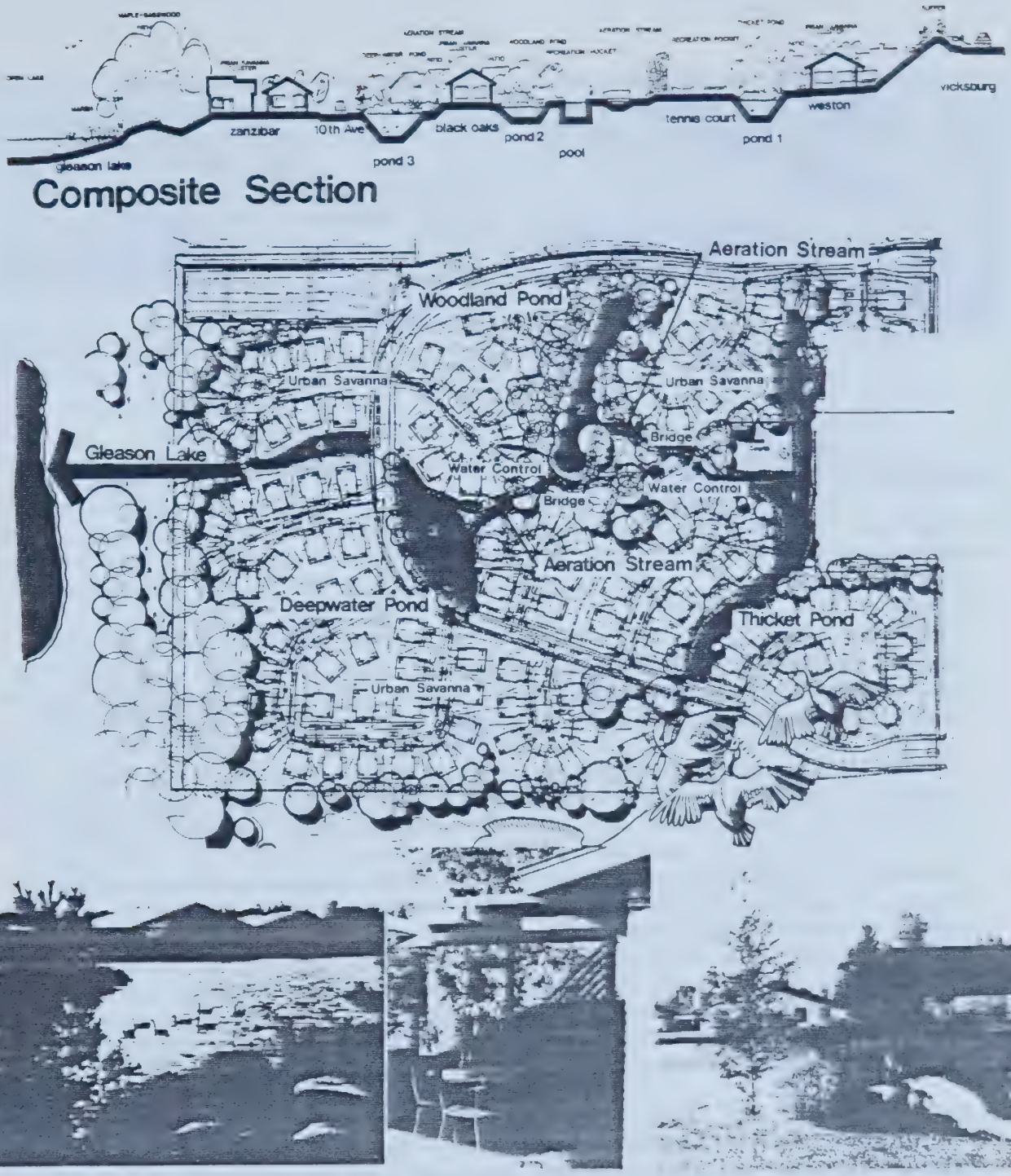
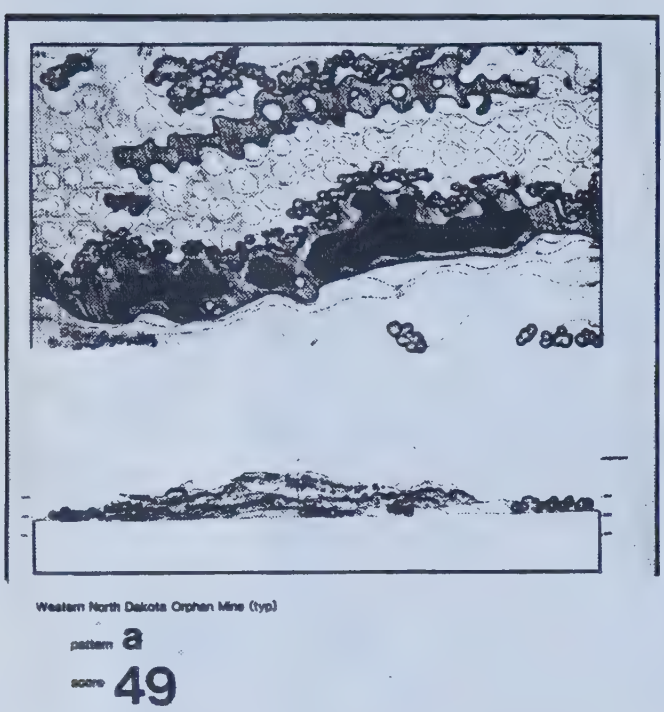
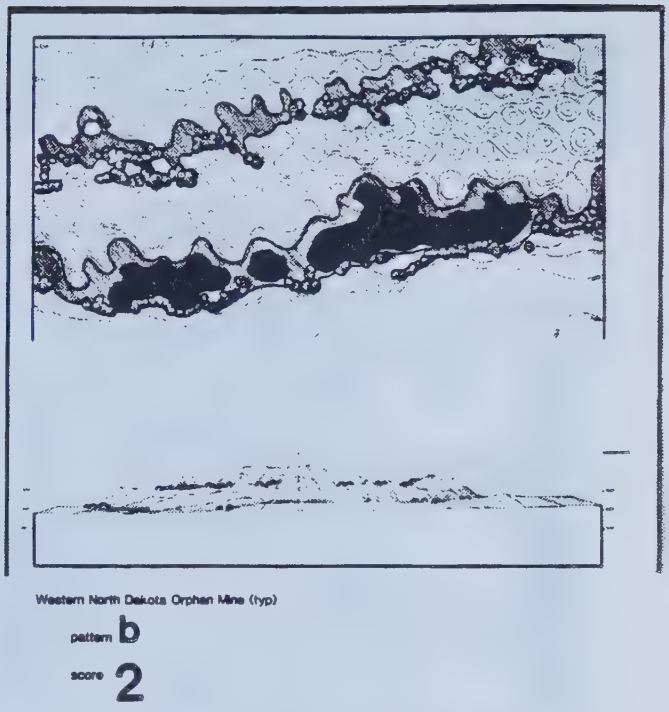


Figure 2. This figure describes an old gravel pit after the pit was developed for housing.

gravel pit for orchard development. In orchard production, post-mining landforms could not be left to chance. Specific design forms and guidelines had to be incorporated into the plan. The plan maximized productivity. In Florida, Chesson (1966) describes phosphate mines being utilized for citrus production. Design teams in the mid-west are consulted to return surface mines to cropland and rangeland. Dietrich (1983) describes similar reclamation practices in Texas. In a unique agricultural study, Ahern (1981) proposed an aquaculture system for a limestone quarry site.





Figures 3 & 4. These drawings illustrate the visual effectiveness of two vegetation patterns upon a typical North Dakota abandoned mine. The higher the score, the more the landscape is preferred.

Recreation is another field where extensive design experience is required. Landscape architects and recreation planners have designed many metropolitan, state park systems and national parks. The head of the National Park Service (NPS) have been landscape architects. Therefore, many design teams would be very knowledgeable concerning the design of post-mining landscapes for recreation. For example, Coates (1985) describes how sand and gravel pits can be developed for recreation. Stealey (1985) describes a project in Ohio being developed for recreation. Zube (1966) describes important landscape design principles to incorporate taconite mines into the native landscape fabric for the preservation of the visual recreational integrity in northern Wisconsin.

Besides functional land-use design such as housing, agriculture and recreation, some landscape architects and artists have had the opportunity to design several post-mining landscapes for purely aesthetic purposes. A recent issue of Landscape Architecture Magazine describes two surface mining projects (Massie 1985 and Dalton 1985) that have been rendered into works of art. Naturally, aesthetic visual quality is also an artistic landscape concern. Visual qualities of surface mines are addressed by ASLA (1978) in a book titled Creating Land for Tomorrow, part of the Landscape Architectural Technical Information Series. This book addresses many surface mining situations. In a state-specific case, Landphair (1980) describes visual resource management for Texas. At the site-specific case level, figures three and four illustrate examples where placement of vegetation can effect public visual perception of reclaimed sites (Burley 1985). Dietrich (1986) and Niran (1985) describes visual

simulation techniques for quarry reclamation. Tlusty (1985) from the University of Wisconsin has given historical, philosophical, and theoretical presentations concerning reclamation and scenic beauty.

In addition to functional and aesthetic site issues, interdisciplinary design teams are knowledgeable concerning a variety of surface mining topics. For example Simpson (1985) reviews pertinent landscape law. Other landscape architects address large regional planning issues concerning surface mining. For example, Dennis Law, a landscape architect for Kansas State University, has published preliminary watershed work for a watershed in Wyoming (Stieg & Law 1985). Ferguson (1985) has addressed watersheds for an Appalachian mine. Yuill (1982) describes a land-use decision methodology for surface mined lands. Morrison (1981) presents research results concerning vegetation establishment on taconite iron ore tailings.

Not only do design teams address post-mining landscapes for non-mining uses, together with surface mine operators they address post-mining surface mining issues. For example Niemann (1985) discusses the design of a landscape for second mining.

To support the dissemination of information to the landscape architectural commodity and to other disciplines, several books concerning reclamation design have been written. The National Sand and Gravel Association has published several books (Bauer 1968, Bauer 1965, Baxter 1969, Jensen 1967, Johnson 1966, Schellie and Rogier 1963). Brian Hacket (1977) edited Landscape Reclamation Practice. Law (1984) wrote Mine-Land Rehabilitation. Cole (et al 1976) published a booklet concerning visual resource management.

The examples described in this paper cut across a broad range of surface mining activities and disciplines. These surface mining activities include phosphate mining, limestone quarry mining and taconite mining. Russel Beatty (1966) describes the reclamation of a surface gold mine operation. Law and Linscott (1981) describe reclamation principles for oil and gas fields. Design services are also utilized in highway reclamation, native landscape restoration and forestry. The team is prepared to integrate the post-mining plan into the larger land-use regional design issues.

Landscape architects and their allied professions are being specifically trained to address the issues associated with surface mining and reclamation. Programs at Platteville Wisconsin, Montana State University, Iowa State University and North Dakota State University are a few of the schools with staff and programs which specialize in surface mining and reclamation. Since reclamation and surface mining are part of larger landscape design issues, many landscape architectural and natural resource programs produce graduates who are trained to address surface mining and reclamation. Programs at Michigan State University, Oklahoma State University and the University of Manitoba are a few of the many schools which conduct design studios where students address surface mining and reclamation issues. To simulate the real world, landscape architectural students and students from other disciplines may collaboratively work upon a studio project.

Students from the United States and Canada have a special educational opportunity to study surface mining and reclamation. Each year landscape architecture seniors and graduate students participate in the National Stone Association and National Sand and Gravel Association reclamation competition. Students work with quarry operators and, sand and gravel operators to learn about surface mining operations. Students prepare site operation analysis diagrams, site improvement drawings and final-use reclamation plans. The students also examine cost analysis of their plans and prepare an extensive narrative. By working with operators, the students gain first-hand practical experience addressing specific surface mining industries.

From these examples, it is quite apparent that landscape architects and their allied professions have gained substantial exposure to surface mining issues and reclamation problems. As a team, they solve real problems for people and create usable post-mining landscapes.

CONCLUSION

Surface mining and post-mining land-use reclamation are part of the larger landscape design and landscape utilization issue. There are at least three surface mining environmental land-use policy issues which require assessment.

1. While society at large is in contact with everyday design decisions, post- surface mining land-use design is complex and requires legally competent design professionals to protect the public's health, safety and welfare. Those states with active surface mines and not requiring legally registered and licensed professionals to prepare post-mining land-use plans may not be adequately protecting the public.

2. Reclamation is absolutely much more than generic landscape revegetation prescriptions (figure 5). Surface mining reclamation laws must recognize that surface mining can be a positive land development action. The post-mining landscape does not have to resemble the pre-mining landscape. Grazing lands can be converted to housing, marginal forested lands can be converted into prime recreational development and marginal agricultural lands can be converted into superb wildlife habitat preserves.

3. To obtain optimum post-mining development, post-mining land-use must be incorporated into coordinated city, township, county, regional, state and federal planning policies and zoning regulations. The designated use of a particular parcel of land is not an isolated issue.

To address these issues, there are numerous opportunities to supplement ones abilities and to discuss post-mining land-use issues. For example, many landscape architecture programs offer site planning courses available to operators, developers, land-owners, other disciplines and governmental employees to increase their sensitivity concerning environmental design. To learn more about obtaining formal

Figure 5. This collection of drawings illustrates the range of possible design solutions for a typical reclaimed sand and gravel site.

education in land reclamation, contact ASLA (American Society of Landscape Architecture) or obtain a copy of A Guide to Educational Programs in Landscape Architecture (Shirvani 1985). To professionally discuss surface mining issues with members of design teams, plan to attend an annual fall ASLA convention and meet the members of the ASLA reclamation committee or attend an ASSMR (American Society for Surface Mining and Reclamation) annual meeting, or attend the annual National Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. In an interdisciplinary and collaborative atmosphere, the continued advancement of reclamation land-use development will continue.

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PLANNING DISPOSAL OF DRILLING WASTES IN ALBERTA - AN ENVIRONMENTAL PERSPECTIVE*

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ABSTRACT

Wastes disposed on the land during oil and gas drilling have potential for serious environmental pollution. This presentation focuses on the environmental investigations that must be undertaken and reviews procedures for environmentally acceptable disposition of drilling wastes. An integrated approach considering environmental conditions along with: initial composition of mud additives; drilling requirements; waste handling, treatment, recycling, disposal; and processing of wastes for other uses can allow effective environmentally safe drilling procedures to be developed.

This paper is based on a recent literature review conducted by the author and associates for the Alberta Land Conservation and Reclamation Council.

INTRODUCTION

A study on the "Disposal of Wastes from Drilling Systems on Public and Private Lands in Alberta" (Leskiw, Reinl-Dwyer, Dabrowski, Rutherford and Hamilton, 1986) was commissioned by the Alberta Government. The study was funded through the Reclamation Review Technical Advisory Committee by the Land Conservation and Reclamation Council via the Heritage Savings and Trust Fund.

The findings and opinions expressed in this presentation are based on the above and are those of the authors, and not of Alberta Environment, Alberta Energy Resources Conservation Board or Alberta Forestry, Lands and Wildlife or any of their representatives.

Specific objectives of the original project which are addressed in this paper are: to identify physical and chemical problems associated with drilling waste disposal based on a literature review and consultation with various agencies; and to develop, test, and demonstrate field application for a decision-making flowchart.

* Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

BACKGROUND ON DRILLING WASTES

Mud Systems

The major drilling mud systems presently used in Alberta are:

Fresh Water Mud Systems - historically about 95% of all wells, used where no special drilling fluid characteristics required. Common makeup is: water, bentonite (gel), carboxymethyl cellulose, lignosulfonates, and polymers; pH is 9-10.

Saline Water Mud Systems - used in the Foothills and in drilling in-situ bitumen wells in NE Alberta. Common make-up is: 20,000 to 40,000 ppm salts (KCl or NaCl) in a water-bentonite-polymer medium, oxygen scavengers to inhibit corrosion; pH is 9.5-10.5.

Invert Mud Systems - water dispersed in diesel oil using emulsifiers, barite, organophylic clay, calcium chloride at about 300,000 ppm. These are very expensive systems and constituents are mostly recovered.

Sumps

Various portions of the drilling fluids will enter a sump unaltered, or altered due to temperature and pressure effects, presence of contaminants, and contamination by materials other than drilling fluids such as lubricants, washing compounds and unidentified organics. As a result, sumps generally contain a complex mixture of organic and inorganic compounds in three distinct phases: (1) thin surficial layer of oil scum; (2) thick "fluid" phase with dissolved components and suspended solids; and (3) bottom layer of "solids", sludge containing settled solids. Horizontal variability may also occur within a sump due to release of the waste from mainly one point.

In most cases, sump volume is largely dependent on depth drilled, about 0.50 m^3 per 1 m drilled, and usually ranges from 1,000 m^3 to 10,000 m^3 per well.

Sump toxicity can be assessed by a 96 hour Trout Test or by a Microtox Test, which are tests used in ecotoxicology to assess lethality of the toxic potential of complex mixtures. In 1983-84 it was found that 60% of nearly 600 sumps tested, out of 11,000 spudded in Alberta, were toxic (ERCB, 1985). Data suggest that sump fluid toxicity is not related to well depth.

Current Disposal

On-lease disposal is regulated by Alberta ERCB (Energy Resources Conservation Board) Guidelines, Interim Directive ID-0G75-2, which are currently under review. Presently sump fluids, other than KCl fluids, under 6,000 barrels in volume may be disposed on-lease, regardless of their chemical compositions or toxicity, given the lease is at least 300 feet from the normal high water mark of a water body. In practice, if it is known that a sump has toxic characteristics, treatment

is required regardless of volume. Volumes over 6,000 barrels are disposed off-lease and have to normally meet, or if necessary be treated to meet, the following criteria:

Chloride Content	<1000 mg/l (if >1000 mg/l, use a spread rate to allow off-lease disposal)
Sulfate Content	<2000 mg/l
Total Dissolved Solids	<4000 mg/l
pH	5.5-8.5
Trout Survival Test	1 of 2 Trout Fingerlings must survive 96 hrs.

Disposal to a subsurface formation is acceptable if that formation is not locally productive of oil and gas, and if the formation water in the disposal zone has a total dissolved solids content greater than 20,000 mg/l. If KCl drilling fluids are used, a disposal plan is requested by Alberta Forestry, Lands and Wildlife which has to be approved prior to lease construction.

The current guidelines only address the fluids part of the drilling wastes: KCl solids disposal is monitored as noted above. Five basic disposal methods are used at present (Lloyd, 1985):

* In pit burial
* Deep trenching or modified deep trenching and shallow trenching
  Standard squeezing
  Surface spreading
  Deep well disposal (not addressed in this study)

(* - not available in the Agricultural Area)

The first two methods have been commonly practiced in the forested areas because tree clearing is minimized in order to maintain the timber base, and topography, proximity to water bodies and suitability of soils restrict the working space. The second and third methods have been commonly used on agricultural land. The fourth method is encouraged as the preferred disposal option because degradation of materials is enhanced by microbial activity and photo-oxidation. The first two methods are now discouraged on forested lands and disallowed on agricultural lands because of lower degradative potential, possible formation of anaerobic decomposition products which are uncontrollable, and potential contamination of groundwater with salts or organics (Lloyd, 1985). The squeezing method, whereby a bulldozer slowly pushes fluids out of one end of the pit by pushing in fill material at the other end leaving a portion of the solids in the pit, is still accepted in Alberta (Lloyd, 1985).

Need for Waste Disposal Planning

A decision-making flowchart was prepared by Leskiw et al. (1986) to assist provincial government field staff, and industry, in selecting optimum methods for environmentally safe disposal of drilling wastes. The phases and steps in the chart, Figure 1, and sections in this

Marginally Suitable - approve the site provided that possible consequences of contamination are not serious (see next paragraph) and appropriate management is specified to mitigate site limitations. Further field investigation and preparation of a waste handling and site reclamation plan (or surface waste disposal plan) may be required.

Unsuitable - find an alternative suitable location.

In these early stages of waste disposal planning the items following (environmental checklist) should be considered with respect to consequences of environmental contamination, albeit subjectively, to gather data for future objective evaluations:

Features Potentially Affected
- Groundwater aquifer
- Watershed - streams, shallow groundwater flow
- Soils
- Vegetation (habitat)
- Wildlife
- Food chain - animal, human
- Adjoining ecosystems
- Land use - cover, productivity

Seasonal Implications - for disposal and revegetation

Impact on people

Cost of future clean-up if necessary

SURFACE WASTE DISPOSAL SITE EVALUATION

Procedures for disposal site evaluation parallel those for sump location evaluation, that is, site selection based on existing information and field inspection, and approval based on site characteristics and environmental considerations. Table 2 provides guidelines for surface waste disposal (also known as land farming). Conditions for site approval are identical to those for sump location. Likewise, consequences of environmental contamination should be considered, going through the environmental checklist.

As an alternative to costly or environmentally risky waste disposal, the operator may change the drilling mud system and additives to minimize negative environmental impacts.

DRILLING WASTE CHARACTERIZATION: QUALITY AND QUANTITY

Major steps to be undertaken to characterize the wastes are summarized as follows:

1. List additives and quantities used in the drilling and treating processes that end up in whole or in part in the sump. Include wastes such as oil, grease, soap, etc. Indicate amount of fluids/wastes disposed elsewhere if applicable. This information should be routinely provided by the drilling and mud treatment companies.

If the spread area is too large an alternative disposal method is needed, such as, treatment, solidification, off-site disposal, or utilization.

4. Select Surface Application Methods

The criteria for selection of application systems and equipment are dependent upon several factors:
- the form of the sludge (fluid, semi-solid or solid)
- the quantity
- the area application rate
- the frequency of application (one time, several times)
- time of year
- topography of area

Surface application is performed either by irrigation or tank vehicle. A fixed irrigation system is best suited where sludges are applied regularly. The tank truck provides flexibility in where to haul and where to apply the sludge. The use of a pumped discharge on the tank allows discharge over a wider area or from a roadway. Subsurface injection is considered if public nuisance from sludge application is a possibility.

The most economical methods for drilling mud sludges are probably surface application by tank vehicle of fluids or spreading of semi-solid sludges.

CONCLUSION

In the author's opinion, the oil and gas industry and regulatory government agencies must pay greater attention to the environmental impacts of drilling wastes, because:
- large volumes of wastes (approximately 5 million m^3 in 1985) are disposed annually,
- many sumps contain toxic fluids (60% of some 600 sumps tested in 1983-84 were found to be toxic) and solids which are probably toxic too but have not been tested routinely to date,
- many sumps have large amounts of salts, extreme pH levels, and excessive concentrations of specific ions, for example, sodium, chloride, sulphate, trace elements and heavy metals, and
- organic compounds which are extremely variable in composition and toxicity may be present in sumps.

This paper and the report it is based on review procedures for environmentally acceptable disposition of wastes based on current guidelines. In fact, there are many "unknowns" and it will take much effort and adequate funding to provide workable alternatives that will minimize potential for serious environmental pollution.

UPDATE ON ONTARIO'S AGGREGATE RESOURCES MANAGEMENT PROGRAM*

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ABSTRACT

At the 1983 annual meeting of the CLRA in Waterloo, a paper was presented detailing Ontario's management strategy for mineral aggregate resources. In keeping with this strategy, a number of developments have occurred in the past four years.

With renewed calls for changes in legislation, the proposed Aggregates Act has been readied once again for introduction into the Legislature. Revisions have been made to the draft bill to reflect organizational changes in government.

What had been referred to as the Mineral Aggregate Resource Planning Policy after receiving Cabinet approval in 1982, is now called the Mineral Aggregate Resources Policy Statement. This as a result of becoming, in 1986, the first formal policy statement approved under section 3 of the new Planning Act.

Promotion of more and better quality rehabilitation continues with research efforts and subsequent publishing of results. Published reports have recently been released; one on pit rehabilitation in northern Ontario. This report recognizes climatic and soil limitations of the north and emphasizes the basics of rehabilitation. A second report is on rehabilitation to fish and wildlife after uses. It is a comprehensive look at rehabilitation to seven major fish and wildlife after uses. Emphasis is on pre-extraction evaluation of site characteristics, the various alternative after uses and post management efforts required to maintain the desired end use. The report offers many useful tips on rehabilitation techniques applicable to fish and wildlife habitats.

Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

MISE À JOUR DU PROGRAMME DE GESTION DES RESSOURCES EN AGRÉGATS DE L'ONTARIO*

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RESUME

Lors de la réunion annuelle de 1983 de la ACRSD à Waterloo, on a présenté une communication donnant le detail de la stratégie ontarienne de gestion des ressources en agrégats minéraux. Un certain nombre d'événements, en rapport avec cette stratégie, se sont produits au cours des quatre dernières années.

À la suite de nombreuses demandes de modification des lois, on a revu à nouveau le projet de loi sur les agrégats pour présentation à l'Assemblée. Les révisions au projet de loi reflètent les modifications apportées à la structure du gouvernement.

La Politique de planification des ressources d'agrégats minéraux, après avoir été approuvée par le conseil des ministres en 1982, s'appelle désormais la Déclaration de principe sur les ressources en agrégats minéraux. C'est la première déclaration officielle de principe, adoptée en 1986, dans le cadre de l'article 3 de la nouvelle Loi sur l'aménagement du territoire.

On continue à favoriser une meilleure réhabilitation en poursuivant des recherches dont on publie ensuite les résultats. On a récemment diffusé les rapports publiés, dont l'un sur la réhabilitation des puits dans le Nord de l'Ontario. Ce rapport tient compte des contraintes découlant des conditions climatiques et géologiques du Nord de l'Ontario et met l'accent sur les principes de base de la réhabilitation. Un second rapport porte sur la réhabilitation de l'habitat des poissons et de la faune après exploitation; il s'agit d'une étude approfondie de réhabilitation en faveur de sept espèces importantes de poissons et de faune après exploitation. On insiste sur l'évaluation avant extraction des caractéristiques du site, les diverses possibilités d'usage après expoitation et les travaux de gestion ultérieurs nécessaires pour parvenir aux utilisations finales voulues. Le rapport offre de nombreuses suggestions utiles sur les techniques de réhabilitation applicables à l'habitat de la faune et des poissons.

Présenté lors de la 12e réunion annuelle de l'Association Canadienne de Rehabilitation des Sites Degrades, université Laurentienne, Sudbury (Ontario), 7-11 juin 1987.

INTRODUCTION

The overall rebound in Ontario's economy has been reflected by the increase in mineral aggregate production in the province from 96 million tonnes in 1982 to 140 million tonnes in 1985. This points to an ever greater need to ensure that land disturbed for the purpose of aggregate extraction be rehabilitated as early as possible to an after-use compatible with the surrounding landscape.

At the 1983 annual meeting of the Canadian Land Reclamation Association held at Waterloo, Ontario, a comprehensive paper (Masham and Wood, 1983) was presented by John Masham of the Ministry of Natural Resources. This paper detailed the Ontario government's past involvement in mineral aggregate resource management and its continuing commitment to rehabilitation. Reference should be made to the 1983 proceedings of the 8th annual meeting for the full details on the development of Ontario's mineral aggregate resource management program current to 1983.

To update this year's meeting delegates on highlights of the past four years, particularly as it applies to pits and quarries rehabilitation, the stage will be set with a short review of the period 1971-83.

REVIEW 1971-1983

The government of Ontario legislated the requirement for rehabilitation of aggregate extraction operations in 1971. The Pits and Quarries Control Act was passed for the purpose of providing rules and regulations that would accelerate rehabilitation and minimize the environmental impact of pit and quarry operations. The Act applies only to municipalities that have been designated by regulation. Over the years additional municipalities have been designated to come under the Act to where, presently, most of southern Ontario and the Sudbury and Sault Ste. Marie areas of northern Ontario are now covered. The Act is administered and enforced by the Ministry of Natural Resources.

Inadequacies of the Pits and Quarries Control Act became apparent over a period of years following problems in administration and enforcement. As a result, the Ontario Mineral Aggregate Working Party was appointed by the Ontario government in late 1975 to examine the operations of the industry and the concerns of the municipalities. The report of the Working Party (Ontario Mineral Aggregate Working Party, 1977), published in early 1977, contained sixty-four recommendations for new policy and legislation.

From these recommendations, the Ministry of Natural Resources has developed a dual approach; two separate but complementary programs in an aggregate resource management strategy for the Province of Ontario

- new legislation to better control the operation of pits and quarries and provide for their rehabilitation; and, a planning policy to provide direction to municipalities in their planning for aggregate resources and the aggregate industry.

The proposed Aggregates Act (then Bill 127) received first and second reading in 1979 and again in 1980 and was referred to a committee of the Legislature called the Standing Committee for Resources Development. There it received a thorough review which resulted in many revisions. However, Bill 127 died on the order paper at the 1981 provincial election and has never been reintroduced.

The Working Party had recognized a reduction in the availability of aggregate resource deposits caused by the development of incompatible land uses on or near these deposits. In 1979 a government committee was established, responsible for preparing an aggregate planning policy. By 1983, the Mineral Aggregate Resource Planning Policy had received Cabinet approval.

Since the passing of the Pits and Quarries Control Act in 1971, the Ministry of Natural Resources has been promoting rehabilitation. Many research and educational programs have been undertaken to assist operators in the rehabilitation of pits and quarries. Prior to 1983, a number of noteworthy rehabilitation reports had been published covering such topics as the use of trees and shrubs, rehabilitation of abandoned pits and quarries and rehabilitation to agriculture.

UPDATE

In 1986, the mineral resources program was shifted from the Ministry of Natural Resources to the new Ministry of Northern Development and Mines. An exception to this shift was the retention of the aggregate resources program with the Ministry of Natural Resources. The Aggregate Resources Section is now part of the Land Management Branch of M.N.R. To accommodate the transfer of the mineral resources program, the Aggregate Resources Section has been given responsibility for two other pieces of legislation regarding aggregates - the Beach Protection Act and part VII of the Mining Act (Crown land aggregates).

The Aggregates Act: To facilitate these organizational changes, revisions have been made to the proposed Aggregates Act to incorporate the Pits and Quarries Control Act, part VII of the Mining Act and the Beach Protection Act under one Act. The result is expected to be a more equitable, consistent and complete approach to regulating aggregate operations in this province.

To compare the extent and scale of operations under the various pieces of legislation the following figures for 1985 are provided:

Legislation	No. of Licences/ Permits	Tonnes (million)
Pits and Quarries Control Act		
- licences	2617	105
- wayside permits	201	6
Mining Act - quarry permits	1500	16
Beach Protection Act - licences	20	0.3

To account for the total 1985 aggregate production in Ontario of 140 million tonnes, the remainder was produced from private land in areas not designated under the Pits and Quarries Control Act. Approximately $6 million of rehabilitation was performed on sites licenced under the Pits and Quarries Control Act in 1986 and approximately $25 million in rehabilitation security is presently being held by the Province of Ontario.

Besides incorporating the Beach Protection Act and part VII of the Mining Act, the proposed Aggregates Act has been developed with the intent of rectifying the following inadequacies of the present Pits and Quarries Control Act with an emphasis on requiring more and better rehabilitation:

- the ambiguous language of a number of sections in the Act make it difficult to administer and enforce
- rehabilitation requirements are inadequate
- the Act does not provide for adequate liaison with municipalities;
- the Act does not provide for remuneration to municipalities to compensate them for inconvenience and some of the costs incurred as a result of pit and quarry operations
- there is no provision to deal with the rehabilitation of abandoned pits and quarries.

There has been mounting pressure for reintroduction of the Aggregates Act from a number of sources, most notably municipalities. The proposed Act has now been readied again for introduction into the Legislature.

Mineral Aggregate Resources Policy Statement: The revised Planning Act which was proclaimed law on August 1, 1983 provides for provincial interest in planning matters to be addressed through Provincial Policy Statements.

What was an already approved planning policy became the first policy statement under the new Planning Act when Cabinet approved the Mineral Aggregate Resources Policy Statement on May 9, 1986. Through the municipal planning process, MARPS will allow the Ministry of Natural Resources to:

- encourage the concept of aggregate extraction as an interim land use activity
- encourage sequential land use and progressive and ultimate rehabilitation with the active extraction area limited to a minimum practical size
- encourage operation of sites in a manner as compatible as possible with surrounding land uses and activities
- encourage all depleted pits and quarries to be returned to a condition suitable for an acceptable after use and compatible with adjacent land uses.

Rehabilitation Research: Since 1983, additional publications and educational material have been put forth by what is now the Aggregate Resources Section of M.N.R.

In 1985, a report entitled "Rehabilitation of Sand and Gravel Pits for Fruit Production in Ontario" (Mackintosh and Hoffman, 1985) was released. This study details the procedures and techniques necessary for the successful rehabilitation to productive fruitlands.

An educational filmstrip titled "A is for Aggregate" was completed in 1985. This filmstrip is intended to help schoolchildren in junior grades understand pit and quarry operations and rehabilitation. Available from Summit Film Productions, Guelph, Ontario, the filmstrip is of use to all those interested in demonstrating both the need and value of aggregate operations, as well as the concept of rehabilitation.

Just recently, three new publications were released by the Aggregate Resources Section. One of these is not rehabilitation oriented but is worth noting. It is called "The Clay and Shale Industries of Ontario" (Guillet and Joyce, 1987). This is an extensive report describing the clay and shale resources of Ontario as well as the manufacturing industries which use these raw materials - brick, drainage tile, floor and wall tile, mineral wool, pottery, etc.

A publication called "Sand and Gravel Pit Rehabilitation in Northern Ontario" (Miller and Mackintosh, 1987) was also released. Its intent is to recognize the special limitations of the north and emphasizes the basics of rehabilitation.

The major limiting factors are:

- general lack of sufficient amounts of topsoil and overburden in most areas
- short average growing season for plants (mean daily temperature above 5.5 degrees C.)

- very low winter temperatures (January average of minus 26 degrees C. near Hearst and Red Lake).

Because of these extreme climatic conditions, along with the harsh local environment for plant growth in gravel pits, vegetation establishment is dependent upon the following:

- proper species selection and adequate fertilization - the report recommends two Ministry of Transportation and Communications standard seed mixtures depending on fertility of the site.

Sandy, Infertile Sites, with Little Topsoil

Materials	Amounts to be Applied Per Hectare
Rye Grain	60 kg
Birdsfoot trefoil (inoculated seed)	32 kg
Canada bluegrass	20 kg
Tall fescue	18 kg
Creeping red fescue	10 kg
Creeping foxtail (coated)	10 kg
Hard fescue	5 kg
Alsike clover	5 kg
8-32-16 fertilizer	350 kg
0-46-0 fertilizer	200 kg
0-0-60 fertilizer	200 kg

Loamy to Clayey, More Fertile Sites

Materials	Amounts to be Applied Per Hectare
Rye Grain	60 kg
Creeping red fescue	55 kg
Canadian bluegrass	27 kg
Perennial rye	15 kg
White clover	3 kg
8-32-16 fertilizer	350 kg

Source: Ontario Ministry of Transportation and Communications, Maintenance Branch. For details on application, consult M.T.C.'s Turf Establishment manual (1986).

- appropriate timing of planting operations - a grass/legume mixture is essential for long-term vegetation success and erosion control on many sites. Legumes are to be planted in the spring only up until mid-June. However, if sloping and topsoiling is carried out in the fall, a temporary cover-crop should be planted to control erosion until the following spring
- sufficient supply of organic material - to control erosion during seed germination and to provide organic matter for plant growth, a straw mulch should be spread on most sites.

The third publication recently released is called "Rehabilitation of Pits and Quarries for Fish and Wildlife (Michalski, Gregory and Usher, 1987). This 59-page report categorizes seven major fish and wildlife habitat ranging from upland wildlife habitat to wetland habitat for waterfowl and fish:

1. commercial game farm
2. wildlife hunting area
3. wildlife protection area
4. waterfowl hunting area
5. waterfowl protection area
6. recreational fish pond
7. commercial fish pond

Field investigations of past efforts to rehabilitate pits and quarries for fish and wildlife after-uses were carried out as was a review of scientific literature on the subject. Lessons learned from this resulted in the identification of six basic steps to successful rehabilitation.

Step 1 - Identification of Preferred After-Uses

A checklist is provided in the report looking at not only the physical attributes of sites, but giving consideration to the operational and economic aspects of maintaining an after-use, some of which may require significant continuing expenditures.

Step 2 - Biophysical Analysis

By comparing the site characteristics with species habitat requirements it can be determined what options are possible and practical. In considering the rehabilitation of pits and quarries to fish and wildlife uses, the report grouped wildlife into three types: aquatic (ducks, muskrat, racoon, etc.), agricultural (pheasant, rabbit, fox, etc.), immature forest (deer, grouse, etc.). Fish are considered in terms of coldwater (trout) or warmwater (bass, catfish, etc.) species.

Step 3 - Site Planning

By considering such site conditions as deposit characteristics, surface characteristics, water conditions, water availability, existing wildlife populations, corridor linkages and surrounding land uses, phasing of the mining operation can be incorporated into the site plan to capitalize on the site characteristics to the benefit of the after-use.

Step 4 - Progressive Rehabilitation

The report provides a number of tips on rehabilitation techniques which especially encourage diversity in landform and vegetation:

- plant material such as tree roots, branches, etc. should be saved for later use in habitat development
- large rocks and boulders should be retained for pond bottoms and shorelines
- unless spring-fed, at least 25% of a pond's area should be 3 m or deeper to avoid oxygen depletion under the ice in winter
- nearshore shallow zones making up about 20% of a pond's area should be created to provide habitat for plant growth and insect colonization. These habitats provide both protection and food for waterfowl and fish.
- overburden should be replaced on pond bottoms to encourage plant growth; topography should be uneven to encourage diversity
- shorelines should be irregular; increased shoreline length increases pond productivity; islands have the same effect and provide waterfowl refuge as well.

Step 5 - Final Rehabilitation

Upon completion of extraction, additional site preparation may be required to enhance fish and/or wildlife habitat

- pond bottoms should be uneven and should be topsoiled before flooding
- pond bottom environments can be enriched by seeding and allowing to germinate before flooding; suspended sediment is reduced and decaying plants provide food source
- introduction of desirable plant species at early stage complemented by natural succession will increase vegetation diversity
- unlike agricultural rehabilitation, topsoil should be redistributed unevenly to encourage habitat diversity for upland wildlife rehabilitation
- different fish species require different types of spawning habitat; areas of shaded deep pools are also important for some species

Step 6 - Resource Management

Long term management of a site following rehabilitation will be necessary for most fish and wildlife after-uses. Re-stocking of fish, periodic drawdown of water to counteract stagnation and weed control may be necessary.

This report also directs those interested in this type of rehabilitation to the various publications and agencies which can provide additional information.

Copies of these reports are available from the Ontario Government Bookstore at 880 Bay Street, Toronto M7A 1N8.

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REVEGETATION OF QUARRIES IN FRANCE - AN EXAMPLE OF RESEARCH APPLIED TO THE UPGRADING OF DEFISCIENT ECOSYSTEMS*

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ABSTRACT

The approach taken by the CEMAGREF in its quarry revegetation program rests upon two keys principles:

a. Regain a sufficient soil fertility to ensure a re-implementation of agriculture or reforestration of degraded land.
b. Make the adequate choice of vegetals and planting techniques, taking into account varying growth parameters inherent in a quarry environment.

Several experimental sites habe been selected. Each of them constitues a small-scale laboratory where techniques are refined and sometimes empirically devised for the purpose of biological improvement of recreated systems.

The scientific and technical investment made on quarry rehabilitation and the results knowhow can then be transposed and adapted to other situations of land-degradation, which we unfortunately encounter: forest fires or degeneration land erosion, fallow land, national energy related programs such as dams and reservoirs; or ski resorts (ski track).

RESUME

L'approche méthodologique réalisée par le CEMAGREF dans le cadre du programme de revégétalisation des carrières repose sur deux idées majeures:

a. Reconstituer des sols dont la fertilité soit suffisante pour assurer le succès d'une reconquête agricole ou forestière des terrains bouleversés.
b. Choisir judicieusement le matériel végétal et les techniques de son implantation en tenant compte de la variabilité des conditions écologiques rencontrées en carrières.

Sur le terrain, différents sites d'expériences ont été choisis. Chacun d'entre eux constitue un petit laboratoire où sont mises au point des techniques dont l'objectif majeur est de contribuer à l'amélioration biologiques des systèmes recréés.

L'investissement scientifique et technique , réalisé sur les carrières et le savoir-faire qui en résulte peut-être, transposé et adapté à d'autres situations de dégradations aujourd'hui préoccupantes: forêts incendiées ou dépérissantes, systèmes agricoles et forestiers soumis à l'érosion ou abandonnés, grands aménagements du territoire.

*Presented at the Twelfth Annual Meeting, Canadian land Reclamation Associattion, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

INTRODUCTION

En France, les carrières occupent actuellement une superficie de 50.000 ha et tous les ans 3500 ha sont transformés en chantiers d'exploitation. Après une longue période d'exploitation inorganisée, les pouvoirs publics et la profession ont pris conscience de la nécéssité de mettre fin à la dégradation de l'espace. A partir de 1974, un programme d'expérimentation de remise en culture agricole et diverses études ont été financés par le comité gestion de la taxe parafiscale sur les granulats. En 1980, le CEMAGREF a été associé à cet effort national. Il s'est vu confié, tout d'abord, la réalisation d'une étude générale pour faire le bilan des reboisements effectués en France sur les carrières et les mines à ciel ouvert. Les conclusions de cette étude ont ensuite servi de base à la mise en place d'un programme expérimental de revégétalisation qui est en cours de réalisation et doit s'achever en 1990.
La présente communication a pour objectif, dans sa première partie, de présenter les principaux acquis scientifiques et techniques obtenus sur ce programme. La deuxième partie présentera deux ensembles de résultats d'expériences dans le domaine de l'amélioration biologique des systèmes recréés.

1ère PARTIE:
LE PROGRAMME FRANCAIS DE REVEGETALISATION DES CARRIERES

GENERALITES

L'approche méthodologique réalisée par le CEMAGREF (BRUN, 1982) dans le cadre de programme repose sur deux idées majeures:

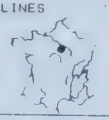
a. Reconstituer des sols dont la fertilité soit suffisante pour assurer le succès d'une reconquête agricole ou forestière des terrains bouleversés par les carrières
b. Choisir judicieusement le matériel végétal et les techniques pour son implantation en tenant compte de la variabilité des conditions écologiques rencontrées en carrières (climat, topographie, géochimie).

Sur le terrain, l'application de ces deux idées a conduit le CEMAGREF a choisir différents sites d'expériences et d'essais pour répondre le plus largement possible aux questions soulevées par cette approche.
Dans le cadre du reverdissement et du reboisement des carrières six sites ont été retenus à ce jour:

- 3 sites alluvionnaires pour des expériences de reboisement
  1981: Sundhoffen (Haut Rhin)
  1983: Boudeau (Dordogne)
  1987: Jablines (Seine et Marne)
- 3 sites en roches massives pour des expériences mixtes de reboisement et reverdissemment:
  1982: Marchaux (Doubs)
  1985: Gourdon (Alpes Maritimes)
  1986: Lepuix-gy (Territoire de Belfort)

Dans le cadre de la remise en culture des carrières:
Un site d'expérience rassemble actuellement les différents essais que l'on peut envisager en matière de reconstitution de sols agricoles. Il s'agit du site alluvionnaire de Passy (Haute-Savoie), installé en 1982.

TABLEAU RECAPITULATIF DES EXPERIMENTATIONS DE REVEGETALISATION DE CARRIERES
SUIVIES ACTUELLEMENT PAR LE C.E.M.A.G.R.E.F. EN FRANCE

	SITES D'EXPERIENCES	SOL — MATERIAUX POUR RECONSTITUER LES SOLS		PLANTES — MATERIEL VEGETAL				THEME PRINCIPAL D'ETUDE ET DE RECHERCHE
		CARRIERE TERRES, STERILES, FINES	HORS CARRIERE DECHETS ORGANIQUES	REBOISEMENT Résineux	REBOISEMENT Feuillus	REVERDISSEMENT	REMISE EN CULTURE	
ALLUVIONS	SUNDHOFFEN	Terre stockée 8 ans 0,25 m et 0,50 m		2 espèces	4 espèces			Mycorhization sur peupliers.
	BOUDEAU	Terre décapée 0,15 m Stérile découverte 0,20 m		3 espèces	3 espèces			Influence d'un apport de terre végétale sur la croissance.
	PASSY	- Terre décapée, épaisseur variable - Fines, épaisseur variable épaisseur testée 0,60 m	Compost d'ordures ménagères broyées				- Prairie temporaire graminée/ légumineuse - Maïs	Reconstitution des sols. Biostimulation lombricienne.
	JABLINES 	Terre décapée 0,50 m Stériles en dépôts > 5 m		4 espèces	4 espèces		Prairie temporaire avant reboisement	Influence d'une culture agricole améliorative avant reboisement.
ROCHES MASSIVES	MARCHAUX	Terre décapée 0,80 m épaisseur testée 1 m	Boues station d'épuration	3 espèces	10 espèces	Lichens. Plantes grimp. Espèces gazon.		Intégration paysagère d'un front de taille de carrière par la revégétalisation.
	GOURDON	Stériles 1 m ou 2 m	Compost d'ordures ménagères broyées	4 espèces	4 espèces			Idem
	LEPUIX-GY	Terre décapée épaisseur testée 0,5 - 1 m - 1,5 m	Compost d'ordures ménagères broyées	3 espèces	2 espèces	Plantes grimp. Espèces gazon.		Idem

MATERIEL

1. Pour reconstituer les sols

Constituants à dominante minérale: il s'agit principalement:

- **des stériles de découverte**, c'est à dire, les horizons minéraux du sol initial
- **des stériles d'exploitation**
- **des matériaux d'apport** dans le mesure où ils contribuent à une réelle amélioration de la fertilité

Constituants à dominante organique: il s'agit principalement:

- **la terre végétale du site,** elle correspond généralement aux horizons pédologiques A_0 et A_1 qui ont été décapés
- **les terres végétales extérieures au site éventuellement,** ces terres doivent faire l'objet d'analyses pour justifier l'intérêt de leur utilisation
- **les amendements organiques.**Parmi les déchets utilisables citons:
  - **les ordures ménagères** broyées et de préference compostées, les risques de pollution doivent être pris en considération pour les carrières présentant une nappe phréatique proche du fond de fouille de l'excavation
  - **les boues de station d'épuration,** les risques de pollution sont en moyenne deux fois plus élevés qu'avec le compost d'ordures ménagères
  - **les résidus de scieries,** effet à long terme pour le fertilité des sols
  - **d'autres déchets** peuvent être utilisés, comme les boues de laiteries, des mélasses diverses, des résidus de pâte à papier.

2. Pour revégétaliser

Plusieurs catégories de végétaux ont été utilisées. Nous distinguerons les végétaux supérieurs des végétaux inférieurs.

Parmi les végétaux supérieurs:

- **Résineux:** pins Laricios, pins noirs, pins sylvestres, pins eldarnica, pins maritimes, Douglas, sapins pectines, épicéas communs, cèdres de l'Atlas, sapins méditerranéens, cyprès
- **Feuillus**: chênes pédoncules, chênes rouges, chênes verts, érables sycomores, érables champêtres, tilleuls, bouleaux, robiniers faux acacias, aulnes à feuilles en coeur, aulnes glutineux, eucalyptus, oliviers de Bohême
- **Plantes grimpantes**: clématites à petites fleurs, lierres, vigne vierge, renouée (polygonum), glycine
- **Plantes herbacées gazonnantes**:
  -Graminées: fétuques, ray-gras, paturin
  -Légumineuses: trèfles

Parmi les végétaux inférieurs:

- **Lichens**: nitrophiles, xérophyles et hydrophyles, au total 6 espèces
- **Mousses**: de milieux calcaires et sec, 1 espèce
- **Fougères** de milieux calcaires et secs, 1 espèce

METHODES

Pour la reconstitution des sols

a) Méthodes de suivis sur tous les sites

- Observation morphologiques
- Description de profils de sols
- Etudes de lames minces au microscope avec lumière polarisée et fluorescente
- Caractérisations analytiques au laboratoire

b) Méthodes d'amélioration biologique de la nutrition azotée sur certains sites par effet racinaire ou biostimulation lombricienne
c) Suivi de la pollution par lysimétrie sur les sites sensibles

Pour les végétaux
a) Sur tous les sites: observations qualitatives de l'état de développement des végétaux
b) Sur les sites reboisés: mesures des élongations de pousses terminales

BILAN DES RESULTATS en 1987

Objectif reverdissement (carrières de roches massives)
L'impact paysager de certains fronts de taille de carrière peut être atténué par l'utilisation des végétaux inférieurs parmi eux:
- **Les lichens transplantés ou bouturés** peuvent patiner les fronts à long terme (t>10 ans). A court terme, ils sont cependant peu efficaces (ex: Marchaux). Il reste à résoudre les problèmes d'approvisionnement et de mise en place de ces végétaux.
- **Les mousses** ont un pouvoir de colonisation et de reverdissement substantiel lorsque les conditions de substrat sont favorables (enrichissement en azote)
- **Les fougères transplantées** ont survécu, leur pouvoir de colonisation étant faible, il reste à résoudre le problème d'approvisionnement et de mise en place.

Parmi les végétaux supérieurs, signalons:
- **Les plantes grimpantes et retombantes** qui se sont avérées efficaces pour dissimuler les fronts de taille, en particulier, on a constaté:
  - une efficacité à court terme pour celles qui se développent sur un support (ex: Marchaux, le polygonum a mis 4 ans pour couvrir 12m de front de taille)
  - une efficacité à plus long terme pour les plantes qui poussent directement sur le rocher (A Marchaux, les plants de lierre ont couvert 4m de hauteur en 4 ans)
- **Les espèces herbacées gazonnantes** peuvent être utilisées en projection avec un substrat ayant un bon pouvoir fixateur par rapport au rocher et un bon pouvoir nutritionnel par rapport à la graine, nous avons expérimenté un mélange intéressant constitué de mortier, de sciure de bois en quantitées équivalentes.

Objectif reboisement (tous types de carrières)
Les plants forestiers traditionnels peuvent être utilisés. Nos expériences nous ont cependant révélé que la survie des reboisements dépend en grande partie de la provenance des plants, de leur état physiologique et de la conformation du système racinaire au moment de la livraison. Les plants forestiers mycorhizés et les espèces arborescentes, fixatrices d'azote atmosphérique, spécialement inoculées offrent des perspectives intéressantes dans les situations pédologiques les plus difficiles, les premiers résultats obtenus sur peupliers (cf. IIème partie) nous encouragent à poursuivre les recherches dans cette voie.

Objectif remise en culture agricole
A Passy en Haute Savoie, nous avons montré qu'il était possible d'avoir sur les surfaces de carrière remises en état des productions agricoles largement supérieures à celles des terrains environnants non dégradés (cf. II ème partie). Les raisons de cette réussite sont liées à la présence sur place de déchets organiques et minéraux en quantités suffisantes permettant de recréer des sols épais et à l'utilisation d'une technique de chantier qui évite tout compactage. A cette occasion, nous avons pu montrer que l'introduction de vers de terre dans de tels sols améliorait sensiblement la fertilité. Ces premiers résultats nous encouragent également à poursuivre les recherches dans cette voie (cf IIème partie).

IIème PARTIE

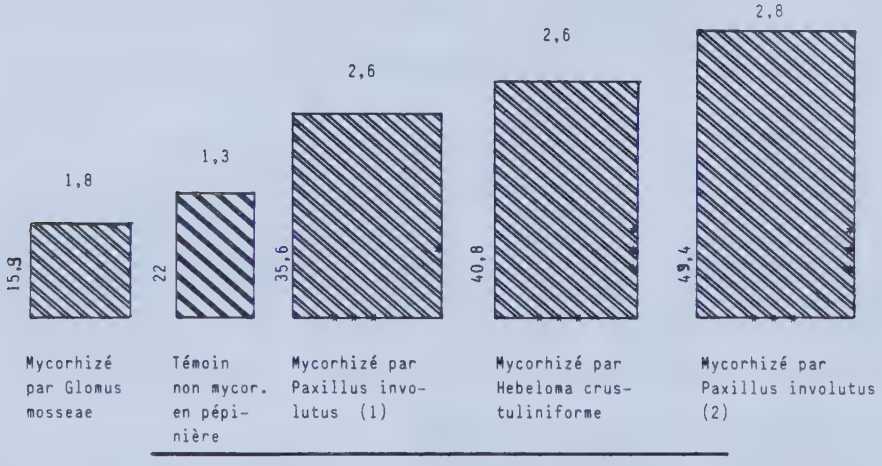
POUR UNE AMELIORATION BIOLOGIQUE DES SYSTEMES RECREES: DEUX EXEMPLES FRANCAIS

Amélioration des conditions de croissance de populus trichocarpa Fritzi Pauley par la mycorhization contrôlée Sündhoffen, Alsace

(Expérience réalisée avec le concours de J. Garbaye du CNRF-INRA de Nancy)

Expérience 1: Plantation en bottes de 12 plants (Cf fig. No 1)
En pépinière, essai de mycorhization contrôlée sur 4 souches mycorhiziennes. 1 endomycorhize (glomus masseae) et 3 ectomycorhizes (paxillus involutus 1 et 2 et hebeloma crustiliniforme)
Résultat: Raxillus involutus (2) est la plus efficace.

FIGURE 1 : EFFET DE LA MYCORHIZATION INITIALE SUR LA CROISSANCE DE 1ère ANNEE
(plantation en bottes de 12 plants)



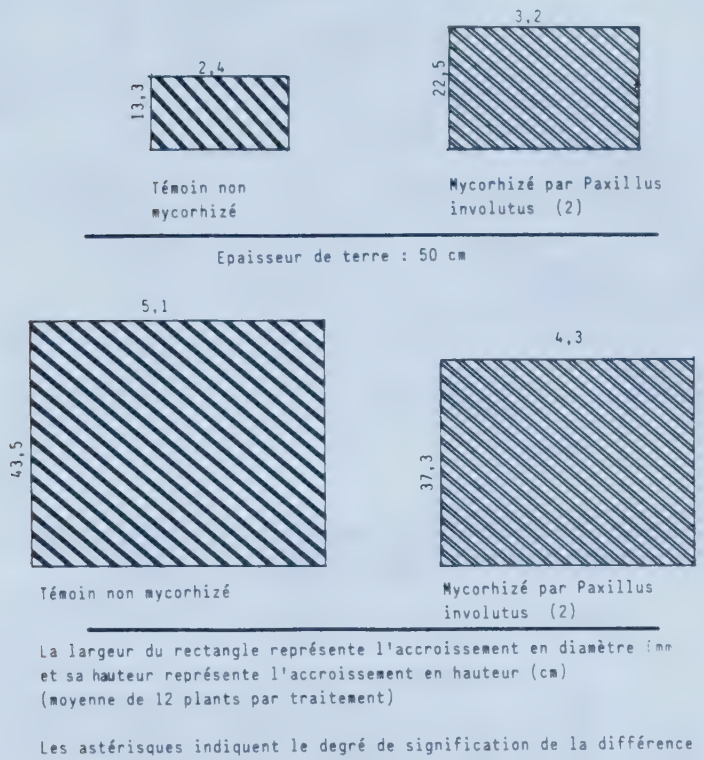
La largeur du rectangle représente l'accroissement en diamètre (mm) et sa hauteur représente l'accroissement en hauteur (cm) (moyennes de 12 plants par traitement)

Les astérisques indiquent le degré de signification de la différence avec le témoin (* : 5 % - *** : 1 °/₀₀)

Expérience 2: Plantation à 2m x 2m sur 2 épaisseurs de sol (Cf fig. No 2)
Résultat: l'effet mycorhization joue dans les conditions de sol les plus limitantes, c'est-à-dire pour une épaisseur de 0,25m

Résultat global des expériences: l'efficacité de la mycorhization avec paxillus inv. (2) sur la croissance des peupliers Fritzi Pauley est maximale dans les conditions nutritionnelles les plus défavorables: forte concurrence (expérience 1), faible épaisseur de sol (expérience 2). Ces résultats sont globaux, ils intègrent aussi bien l'efficacité propre du champignon mais aussi son infectivité et sa compétitivité. L'expérience n'a pas pu être poursuivie à cause des inondations.

FIGURE 2 : EFFET DE LA MYCORHIZATION INITIALE SUR LA CROISSANCE DE 1ère ANNEE (plantation à 2 m x 2 m)



La largeur du rectangle représente l'accroissement en diamètre (mm et sa hauteur représente l'accroissement en hauteur (cm) (moyenne de 12 plants par traitement)

Les astérisques indiquent le degré de signification de la différence avec le témoin (* : 5 % - * * * : 1 °/$_{oo}$)

Amélioration des sols agricoles reconstitués par introduction volontaire de lombriciens efficients.
(Expérience réalisée avec le concours du Laboratoire de Zooécologie du sol de l'INRA à Montpellier. Prof. M. BOUCHE).

Expérience 1: Reconstitution de sols après décapage; BRUN (1986)
Utilisation de la terre naturelle du site, de compost d'ordures ménagères broyées et des fines de lavage. Mise en place par la technique dite des bandes non compactées, plusieurs formules de sols reconstitués testées associant 2 ou 3 des matériaux de base (cf fig. No 3).
Résultats: Les productions obtenues avec ou sans irrigation sont bonnes à excellentes. En situation de non irrigation, l'incorporation de fines de lavage au sous-sol permet un gain significatif de productivité par rapport au témoin (cf fig. No 4).. Cette technique a été préconisée pour des situations de carrières ou de dégradations analogues.

Expérience 2: Introdution de lombriciens; BRUN (1987), HEIDET (1987)
Un mélange efficient de lombriciens collectés manuellement à proximité du site d'expérience a été introduit sur des placettes circulaires de 1m^2 (cf fig. No 5). L'évolution des caractéristiques pédologiques majeures des plots d'expérience (témoin), des placettes d'introduction (1m^2) et des turricules a été effectué pendant deux saisons. La moyenne des résultats a été comparée par couples de caractéristiques étudiées.

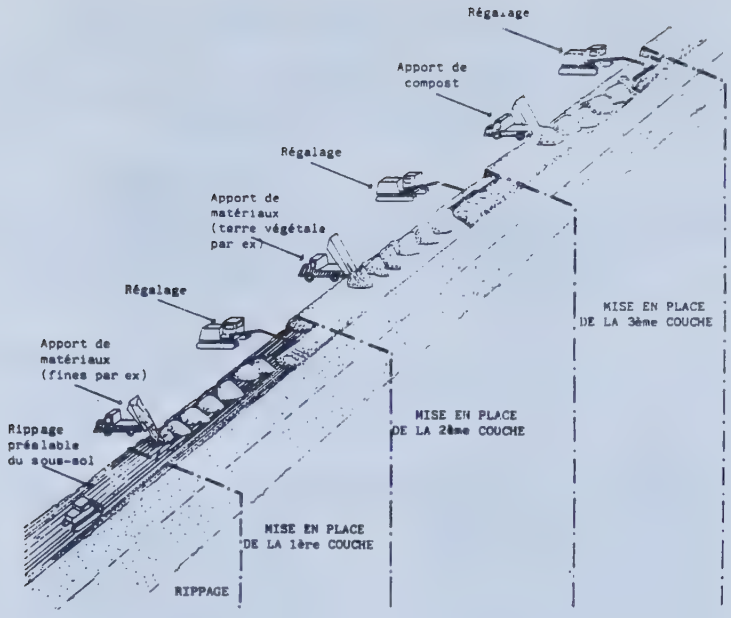

Régalage
Apport de compost
Régalage
Apport de matériaux (terre végétale par ex)
Régalage
Apport de matériaux (fines par ex)
Rippage préalable du sous-sol
MISE EN PLACE DE LA 3ème COUCHE
MISE EN PLACE DE LA 2ème COUCHE
MISE EN PLACE DE LA 1ère COUCHE
RIPPAGE

Figure 3 : Schéma de mise en place de l'essai de Passy (BRUN, 1986)

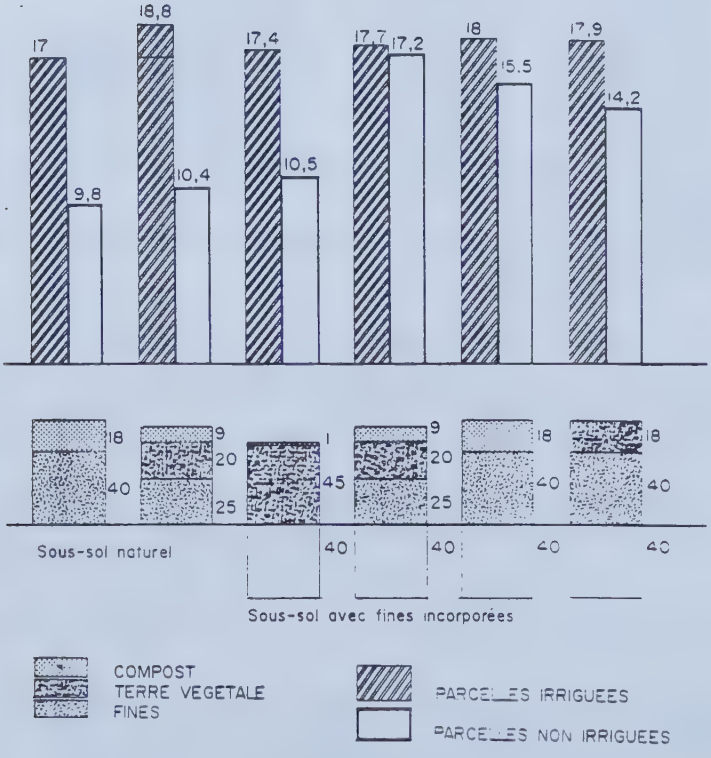
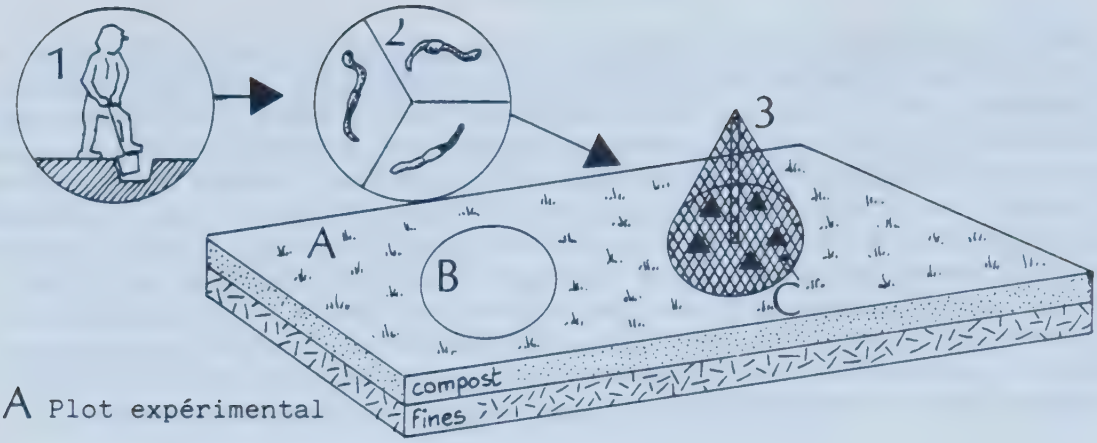


Figure 4 : Rendement de Maïs ensilage en tonnes de matière sèche par hectare



A Plot expérimental

B Zone test préparée pour l'innoculation

▲ Turricule

C Parcelle biostimulée

Figure 5 : Biostimulation lombricienne à Passy

Méthode utilisée pour les plots expérimentaux

1. Prélèvement dans un terrain naturel
2. tri des espèces lombriciennes efficientes
3. inoculation du terrain récepteur protégé par un filet contre la prédation avicole

	Turricules/ Parcelles		Parcelles/ Plots	
	automne 83	printemps 84	automne 83	printemps 84
MO	augmentation	augmentation	sans changement	sans changement
N	augmentation	augmentation	sans changement	sans changement
C/N	augmentation	diminution	sans changement	sans changement
Is	augmentation	-	sans changement	sans changement
pH	diminution	diminution	sans changement	sans changement
CEC	augmentation	augmentation	sans changement	sans changement
CaCO3	diminution	diminution	sans changement	sans changement
K	augmentation	augmentation	sans changement	sans changement

Tableau 1 : Evolution des caractéristiques pédologiques des parcelles

CONCLUSION

Les sites d'expérience retenus dans le cadre du programme d'études et de recherches, mis en place et suivi par le CEMAGREF, pour la revégétalisation des carrières, sont autant de laboratoires de mise au point des techniques de reconstitution de sols et de revégétalisation en conditions difficiles. Les techniques d'amélioration biologiques des systèmes recréés en carrières sont prises en considération avec un intérêt grandissant pour d'autres situations de dégradations préoccupantes aujourd'hui. Face à la diminution de fertilité des systèmes agricoles intensifs ainsi qu'à la déprise agricole de surfaces considérables et face aussi aux dégradations des écosystèmes forestiers (dépérissements, incendies), une demande sensible se manifeste. Seule une collaboration interdisciplinaire nationale et internationale sur ces problèmes majeurs d'environnement permettra de relever ces défis.

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New Methods of Cultivation of Degraded Soils And Steep Slopes Resulting from Mining

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Arrangement:

I Introduction

II Description of recultivation problems in mining

III Prevailing methods and their limits

IV The FRISOL method

1. Application practicability
2. The individual working steps of the FRISOL method
3. Which tasks are accomplished by the FRISOL method?
4. The FRISOL method colloid technology

Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario

June 7 - 11, 1987

I INTRODUCTION

The mining industry is affecting the environment to a great extent and leaving large areas which must be re-integrated into the landscape by means of effective recultivation methods.

II DESCRIPTION OF THE RECULTIVATING PROBLEMS IN MINING

1. Mining waste dumps show an extreme micro-climate. During the summer high temperatures of up to 65° Centigrade and more can be reached, whereby daytime temperatures can deviate as much as 45° and more.

2. The waste dumps are often isolated from ground water and therefore not capable of storing much water. In respect to their water household, they solely depend on rain water. Part of the rainfall seeps away while the rest just runs off the surface of slopes. Water for plants is only available from absorbed or capillary stored sources.
   In regard to rough soil relations, only little water can be stored. In addition to this, the little water present in the ground is subject to intense deviations.

3. Freshly deposited waste materials are, depending on their geological source, subject to rapid weather wear.
   Waste material from pit coal mines, for example, weathers very rapidly. This is due to the high content of slaty soil.

4. Mining waste rock is distinguished by high pH values which are either extremely sour (below pH 3) or extremely basic (over pH 9). See the following examples:
   a) Waste material from the coal mines in the Ruhr area of Germany
      pH values 2 - 3
   b) Waste material from the pit coal range of Aachen, West Germany
      pH values 8 - 10
   c) Waste material from the soft coal mines of Helmstedt, Germany
      pH values 2 - 3
   d) Waste material from the ore mines of the Harz mountains, Germany
      pH values 4 - 5
   e) Soft coal ashes
      pH values 11 - 12
   f) Blast furnace slag
      pH values 11 - 12

Within only a few years the pH values of e.g. freshly dumped waste from bituminous coal mining will drop from initially pH 7 to values of about pH 3. This pH value drop is accompanied by extreme short term variations and is due to pyrite.

5. These extreme pH values are often caused by pollutants contained in the soil. Waste material from bituminous coal mines, for example, have proportionally high contents of sulphur compounds (pyrite, marcasite, hence ferric sulfide), which change to sulphuric acid due to oxidation. Ore waste rubble is additionally charged with high contents of heavy metals.

6. The sterile waste materials are void of biologically decomposive organic elements (e.g. humus). As the organic elements are the source of supply for nitrogen and phosphorus there exists an acute failing of nitrogen and phosphorus. In addition to this, there is usually a shortage of calcium, potassium and magnesium at such locations.

7. In addition to the meagre content of nutrients, the materials which have been mentioned are hardly capable of accumulating nutrients. This is due to the lesser content of soil interchangers (huminous materials, argillaceous earth, silicates). The little nutrient content to be found in the material is washed away by rain. The lack of soil interchangers also has a negative influence on the soil reaction.

8. The organisms existing to a great extent in healthy soils (soil bacterium, soil fungi, algae, lower animal species, insects etc.), which contribute largely to stable soil activity are normally missing in such problematical locations. The self-regulating forces of the soil just do not function here.

9. Due to the failing of a vegetation coverage, water and wind can wash away, respectively drift off materials from sloping surfaces. High erosion occurances are the normal result.

III PREVAILING RECULTIVATING METHODS AND THEIR LIMITS

Conventional hydro-methods or mulching methods, whereby seeds are added to water and in a combination with mineral fertilizers and mulch material are spread over sloping surfaces, are only capable of solving part of the problems mentioned. These methods can be applied at better locations with success. However, at poor locations they become more and more ineffective with the growing number of problems.

Mineral fertilizers, applied in connection with a conventional hydromethod, are rapidly washed away on poor soil conditions. After only a few weeks, the nutrient supply has been consumed. In such cases, long term fertilizers combined with colloids must be applied.

The lack of successes achieved by the conventional recultivation methods led to the requirement of the development of specific methods for all problematical locations. The newly developed FRISOL method has made it possible to close this gap in the recultivation technique successfully.

IV THE FRISOL METHOD

1. APPLICATION PRACTICABILITY

With the aid of the FRISOL method the following problematical locations can be successfully reclaimed:

- Dumps from bituminous and soft coal mines
- Blast furnace slag and power station ashes
- Ore waste material charged with heavy metals
- Highly acid and extremely basic grounds
- Gypsum keuper and silicate lacking red sandstone
- Sterile and parch endangered sands
- Exploited and highly aciduous forest soils
- Salt charged soils, e.g. road-side areas or sea water polluted sands
- Road cuts, shore areas and rocky areas.

Furthermore, the application of the FRISOL method on less problematical soils improves the recultivation success to such an extent that the use of the FRISOL method here is of great advantage for the long term vitality and stability of the vegetation existence. The application of the FRISOL method increases the nutrient storage capability, the water storage capacity of the soil, the assurance of a long term continuous nutrient supply, the activation of the soil life, the stimulation of the fungi growth and influences the root growth positively.

2. THE INDIVIDUAL WORKING STEPS OF THE FRISOL METHOD

2.1 Local inspection of the location with an ecological valuation. This examination includes, from case to case, the micro-climate, the warmth and water household of the soil, the mineralogical composition of the substrate, the nutrient household, the nutrient storage capability, the soil biology and the extent of natural vegetation.

2.2 Necessary soil analysis carried out by authorized research institutes.

2.3 Compilation of a location specific seed mixture.

2.4 In cases where the accomplished examinations are not sufficient for a location specific prescription, pot tests in a greenhouse, or in the open are initiated. With the assistance of these tests the recommended prescriptions can be optimized.

2.5 Correct and professional execution of all the necessary recultivation measures.

3. Which tasks do the FRISOL mixtures accomplish?

The FRISOL mixtures employed in the FRISOL method accomplish the following vegetation technical tasks:

- Creation of an ecologically sensible vegetation technology with the application of specific seed mixtures.

- Ensuring the nutrient needs after germination by the application of fast flowing organic fertilizers.

- Ensuring the long term nutrient needs by application of long and slow release organic fertilizers.

- Gradual build-up of a humus layer by the use of an applicable bio-mass which, due to the biological decomposition process, is changed into permanent humus. This process is intensified by the production of bio-mass by the vegetation coverage itself (sprout and root growth).

- Soil life activating by encouraging of fungi and soil bacterium growth.

- Improvement of the nutrient storage capability (cation interchange capacity) by adding mineral and organic colloids (exchangers) to the soil. With the aid of such ingredients, it is possible to counter salt and heavy metal problems in the soil.

- Achieving an immediate erosion safeguard by using an organic, degradable soil stabilizer. The fixed layers remain water permeable. Depending on the gradient of the ground, fibres are added to increase the function of the fixing materials. The task of erosion safeguard is subsequently taken over by the stable and deep-rooted layer of vegetation.

- Raising the water storage capacity by using swelling substances which increase the capillary capacity after penetrating into the pores of the soil.

- Improvement of the buffer capacity by applying additives, such as e.g. lime for acid soils.

So the FRISOL method offers a noticeable improvement of previous reclaiming techniques and produces the essential requirements for reclaiming problematical areas which, in the past, remained uncultivated or poorly cultivated.

4. THE FRISOL METHOD COLLOID TECHNOLOGY

Soil colloids, also known as interchangers, accomplish manifold tasks in the soil. Among other things they play a leading part in creating soil structure. Due to their electrical charges, they store cations, or anions, improve the water household of the soil by filling the pores with gel coagulation and act as a buffer zone for the soil chemistry (pH values nutrient dynamics, osmotic values of the soil solution, redox potential, etc.).

Soil colloids are of mineral or organic origin. Among the known colloids are, for example, silicates, ferro- and aluminium oxides and hydroxides, acetates, humin materials, polysaccharides and polyuranides.
In most of the mining waste materials, as well as in crude soils in general, colloids are lacking almost completely, resulting in all of the disadvantages connected to this state.

With the help of the FRISOL method it is now possible to create a colloid system in such soils. One of the main components of the FRISOL mixtures is a combination of mineral and organic colloids based on silicates, polysaccharides, phosphates and nitrogen bases. Together with further products these colloids are sprayed in a liquid form and penetrate into the soil. They then remain in the liquid form, or change into gel, depending on the molecule structure. The highly molecular gels are ponderous and offer storage space for water and nutrients. The increased water household capacity lengthens the growth phase of the plants during drought periods and therefore improves the growing conditions noticeably.

The electrical charges of the colloids cause ions to be stored. A part of the nutrient salt concentration contained in the liquid soil solution can be stored by the colloids during increasing drought periods, whereby the increase of the osmotic values of the soil solution is retarded. They can use the water contained in the soil more effectively as the difference between the osmotic values of the soil and the plants remains slight.

A further task carried out by the colloids is the storage of ions thereby making them unavailable for the plants. Therefore with the help of the FRISOL technology the damaging effects of salt and heavy metals can be reduced making it possible for these burdened soils to be reclaimed with greater success.

EARLY SUCCESSIONAL RHIZOSPHERE FUNGAL POPULATIONS IN DISTURBED SEMI-ARID ECOSYSTEMS*

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ABSTRACT

Resource competition between different plant species may result from physiological characteristics that affect microbial development and nutrient availability in the rhizosphere. In the present study, fungal populations, diversity and the community composition of fungal groups in the rhizosphere and nonrhizosphere of several late successional perennial plant species (Hilaria jamesii, Sporobolus airoides, Agropyron smithii and Atriplex canescens) were evaluated at disturbed sites in New Mexico after 0.25, 1.25 and 2.25 years, and in Colorado after 0.25 and 1.25 years of plant growth. Fungal populations, diversity and the composition of fungal groups changed between rhizosphere and nonrhizosphere zones, plant type, and the disturbed study areas with ecosystem development.

INTRODUCTION

Most studies of ecosystem development have focused on plant responses and interaction, with a lesser emphasis given to below-ground root production and microbial processes, especially in the rhizosphere. This approach limits any evaluation of the potential interactions between plant roots and their associated microflora. The ability of different plant types in a mixed community to be more successful in nutrient aquisition may be a reflection of physiological differences that affect microbial development in the rhizosphere. In this study, microfungal populations, diversity and the composition of fungal groups were evaluated during initial plant community development.

MATERIAL AND METHODS

Microfungal populations were determined from rhizosphere and nonrhizosphere samples of late successional perennial plant species at two disturbed sites. The disturbed site in New Mexico was reclaimed in 1982 by grading and leveling the spoil material, spreading stockpiled topsoil material 20 to 30 cm deep over the recontoured spoil, mulching with 4.5 MT of grass hay ha^{-1} crimped 15 cm deep, fertilizing with 72 kg N and 90 kg P ha^{-1}, seeding with native plant species and irrigating for two growing seasons. Rhizosphere material was collected from Hilaria jamesii (HIJA), Sporobolus airoides (SPAI)

*Presented at the Twelfth Annual Meeting, Canadian Land Reclamation Association, Laurentian University, Sudbury, Ontario, June 7-11, 1987.

and Atriplex canescens (ATCA) after 0.25, 1.25 and 2.25 years of plant growth. The disturbed site in Colorado was mechanically disturbed by stripping the native vegetation and top 3 to 4 cm of soil. The site was fertilized with 100 kg N and 100 kg P ha^{-1}. The rhizosphere of Agropyron smithii (AGSM) was sampled after 0.25 and 1.25 years of plant growth. At both sites rhizosphere (0 to 7 cm from the stem of the plant) and nonrhizosphere (30 cm away from the stem of the plant) samples were collected to a depth of 13 cm.

Rhizosphere microbial populations were estimated by methods similar to those described by Lockhead (1940) and Starkey (1956). Fungal groups were isolated by evenly distributing 1-ml of a 10^{-3} dilution over the surface of rose-bengal-streptomycin agar (Martin, 1950). Ten plates were inoculated for each composited soil sample, and incubated at 25°C for 7 days. Fungal groups were identified using the taxonomic guides of Barnett and Hunter (1972), Barron (1968) and Gilman (1968). Diversity was calculated using Shannon's index of species diversity, which estimates community richness as:

$$H = \sum_{i=1}^{k} pi \log pi$$

where pi = the proportion of group i in the sample, and k = the number of groups. The corresponding test for evenness is:

$$J = H/H_{max}$$

where H_{max} = the maxium possible diversity.

RESULTS

Populations of fungi in the rhizosphere and nonrhizosphere of HIJA, SPAI, and AGSM and in the nonrhizosphere of ATCA generally decrease with reclamation age (Table 1). In contrast, populations of fungi in the rhizosphere of ATCA significantly increase with age. Also, after 2.25 years of plant growth the fungal populations in the rhizopshere of ATCA were significantly higher than the fungal populations in the rhizosphere of HIJA or SPAI. The diversity and evenness of fungal groups in the rhizosphere and nonrhizosphere of HIJA, SPAI, and ATCA generally increase with age (Table 2 and 3). There were no real apparent differences in the diversity of fungi in the rhizosphere of HIJA, SPAI, or ATCA compared to their nonrhizosphere zones after only 0.25 years of growth. After 2.25 years, however, the diversity of fungal groups in the nonrhizosphere soil were found to be higher compared to the diversity in thr rhizosphere of HIJA, SPAI, or ATCA.

Dominant fungal groups changed between plant species, and between rhizosphere and nonrhizosphere zones as the age of the plant increased from 0.25 to 2.25 years. Chrysosporium was the dominant fungal group isolated in the rhizosphere and nonrhizosphere zones of HIJA, SPAI, and ATCA after 0.25 years. After 2.25 years the dominant fungal group in the rhizosphere of HIJA and SPAI was Aspergillus, whereas Penicillium was the domiant fungal group in the rhizosphere of ATCA.

In contrast to ATCA, the dominant fungal group in the rhizosphere of AGSM after only 0.25 years was Penicillium. Chrysosporium, however, was the second dominant fungal isolate found in the rhizosphere of AGSM after 0.25 years.

DISCUSSION AND CONCLUSIONS

To date, few studies have been concerned as to the influence of the rhizosphere in strip-mined spoils, as the majority of microbial studies associated with reclamation research have been concerned with the acquisition of baseline data in nonrhizosphere soil, and have been oriented toward problem identifying. The rhizosphere of plants may be of particular importance in the stabilization of mining spoil where soil properties are unfavorable in the surrounding spoil for microbial growth (Cundell, 1977). It is, therefore, important to elucidate the process of rhizosphere development in disturbed lands, in relation to the type of disturbance as well as to the utilization of plant nutrients which may be added to these environments, and the successional status of the plants functioning in particular ecosystems.

The present preliminary study compared microfungi population responses between rhizosphere and nonrhizosphere zones of late verses late successional plant types during the early stages of ecosystem development. It was shown that fungal populations increased in the rhizosphere of Atriplex canescens with age, while the populations of fungi in the rhizosphere of Hilaria jamesii, Sporobolus airoides and Agropyron smithii decreased with time. In contrast, the diversity of fungal groups in the rhizosphere and nonrhizosphere generally increased with age. There were no apparent differences in the diversity in the rhizosphere of Hilaria jamesii, Sporobolus airoides, and Atriplex canescens compared to the nonrhizosphere after only 0.25 years. After 2.25 years, however, the diversity of fungal groups in the nonrhizosphere were higher compared to the rhizosphere of all the plants studied. A higher diversity was related to lower nutrient availability. Different fungal groups dominated the rhizosphere and nonrhizosphere zones, and were dependent on the type and age of the plant, as well as on nutrient additions.

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Table 1. Fungal propagules in the rhizosphere and nonrhizosphere of plants growing on disturbed sites in New Mexico and Colorado (10^{-3} g^{-1}).

	New Mexico			Colorado
	HIJA	SPAI	ATCA	AGSM
0.25-year-old				
R[1]	414 a A[2]	460 b A	360 c A	.353 a A
NR	110 b	91 c	82 d	5 c
1.25-year-old				
R	148 b C	879 a B	1929 b A	138 b C
NR	42 c	24 d	27 d	4 c
2.25-year-old				
R	71 c B	91 c B	14339 a A	
NR	13 d	10 d	28 d	

[1] R = rhizosphere; NR = nonrhizosphere

[2] Means within the same column followed by the same lower case letter are not significantly different at the 5% probability level by the L.S.D. test. Similarly, means within the same horizontal row followed by the same upper class letter are not significantly different.

Table 2. Fungal diversity in the rhizosphere and nonrhizosphere of plants growing on disturbed sites in New Mexico and Colorado[1].

	New Mexico			Colorado
	HIJA	SPAI	ATCA	AGSM
0.25-year-old				
R[2]	0.68	0.72	0.82	1.03
NR	0.79	0.75	0.93	0.83
1.25-year-old				
R	0.93	0.73	0.40	0.91
NR	0.78	0.68	1.01	1.00
2.25-year-old				
R	1.04	0.78	0.98	
NR	1.14	1.15	1.15	

[1]Diversity calculated from isolates occurring on ten 1:1000 soil dilution plates.
[2]R = rhizosphere; NR = nonrhizosphere

Table 3. Fungal evenness in the rhizosphere and nonrhizosphere of plants growing on disturbed sites in New Mexico and Colorado.[1]

	New Mexico			Colorado
	HIJA	SPAI	ATCA	AGSM
0.25-year-old				
R[2]	0.57	0.60	0.65	0.74
NR	0.69	0.61	0.74	0.66
1.25-year-old				
R	0.81	0.61	0.37	0.75
NR	0.62	0.63	0.79	0.78
2.25-year-old				
R	0.76	0.70	0.73	
NR	0.85	0.82	0.83	

[1]Evenness calculated from isolates occurring on ten 1:1000 soil dilution plates.
[2]R = rhizosphere; NR = nonrhizosphere.

Table 4. Major fungal groups in the rhizosphere and nonrhizosphere of plants growing on disturbed sites in New Mexico and Colorado.

	HIJA	SPAI	ATCA
0.25-year-old			
R[1]	Chrysosporium/Penicillium	Chrysosporium/Penicillium	Chrysosoporium/Stachybotrys
NR	Chrysosporium/Penicillium	Chrysosporium/Aspergillus	Chrysosporium/Chaetomium
1.25-year-old			
R	Penicillium/Chaetomium	Penicillium/Chaetomium	Myrothecium/Chrysosporium
NR	Chaetomium/Penicillium	Penicillium/Chaetomium	Chaetomium/Myrothecium
2.25-year-old			
R	Aspergillus/Penicillium	Aspergillus/Chaetomium	Penicillium/Chrysosporium
NR	Aspergillus/Penicillium	Chaetomium/Aspergillus	Aspergillus/Fusarium

[1]R = rhizosphere; NR = nonrhizospehre

Table 4. (Continued)

	AGSM
0.25-year-old	
R	Penicillium/Chrysosporium
NR	Penicillium/Trichoderma
1.25-year-old	
R	Penicillium/Fusarium
NR	Penicillium/Acremonium

APPENDIX

REGISTRANTS AT THE 12 th ANNUAL MEETING

OF THE

CANADIAN LAND RECLAMATION ASSOCIATION

SUDBURY, ONTARIO

JUNE 7-11, 1987

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